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**G E O L O G Y,**  
**INTRODUCTORY, DESCRIPTIVE, AND PRACTICAL.**





# G E O L O G Y,

INTRODUCTORY, DESCRIPTIVE, & PRACTICAL

BY

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<sup>a</sup> This fossil is figured in the text as one of a group of Foraminifera.

<sup>b</sup> The two fossils thus referred to are incorrectly named in the text. The *Cristellaria* there appears as a *Polymorphina* (g), and the *Polymorphina* as a *Fronculina* (h). I regret also to be obliged to apologise for the incorrect drawing of these and one or two other of the fossils figured in this volume. The sketches were taken from the actual specimens, but the finished drawings were unfortunately not proceeded with till afterwards, and at a distance from the specimens. With a very few exceptions, however, the representations of fossils may be perfectly depended on.



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The asterisk (\*) attached to the name of a Fossil denotes as before, that the drawing is from a specimen in the Cambridge Geological Museum. The mark (‡) is placed before the names of Fossils figured from Mr. Bowerbank's collection, and the double asterisk (\*\*) indicates a drawing from a specimen in the British Museum.

### LIST OF THE WORKS REFERRED TO IN THE INDICES.

- a The Transactions of the Geological Society of London.
- c Recherches sur les Poissons Fossiles, par L. Agassiz.
- o De la Beche's report on Cornwall, Devon, and West Somerset.
- s Bowerbank's Fossil Fruits of the London clay.
- t Schmerling's "Ossements Fossiles des cavernes de Liège."
- u Buckland's Reliquiæ Diluvianæ.
- v Owen's account of the Mylodon.
- w Lyell's Elements of Geology.
- x Macculloch's Western Islands of Scotland.
- y Forbes's Travels in the Savoy Alps.
- z Burat's "Geologie Appliquée."
- aa Appendix to Report of Commissioners. "Childrens' Employment Commission."
- bb Transactions of the Northumberland Natural History Society.
- cc Piot's Mémoires sur l'Exploitation de Houille de Newcastle.
- dd Fossil Fuel.
- ee Whitley's Agricultural Geology.
- ff Scrope's Account of the Extinct Volcanoes of Central France.
- gg Picturesque Views of Coal-mines.

NOTE.—The total number of species of fossils figured is 221, and of these 190 were drawn from actual specimens.

The number of diagrams is 103, and the number of miscellaneous and Picturesque illustrations, 42.



# GEOLOGY:

INTRODUCTORY, DESCRIPTIVE, AND PRACTICAL

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## PART THE SECOND—DESCRIPTIVE GEOLOGY.

THE GEOLOGY OF THE TERTIARY PERIOD.

### CHAPTER XXXIV.

ON THE CLASSIFICATION OF THE TERTIARY STRATA.

IN bringing to a close the last volume, and with it the account of Palæozoic and Secondary Geology, I took occasion to observe that, with the Cretaceous rocks, the Geologist reaches, as it were, the termination of that period in the history of the earth to which the character of antiquity belongs, and that this ancient part of Descriptive Geology is succeeded by another, in which all the types and resemblances are those of existing nature.

It is not easy for the young Geologist—for him I mean who is only commencing to study the former condition of the earth and its inhabitants—to realise to himself in its full importance the amount of change thus indicated. Some notion of it may indeed be obtained by analogy, and by considering the difference, of which every one is sensible, between those periods in man's history which are called ancient, and those we denominate modern; but such

a comparison is necessarily very imperfect, although in each case there is a known and evident succession, broken and interfered with by the deep obscurity of an intermediate period.

But this period, truly a dark age in the physical history of the globe, has been hitherto unrelieved by any ray of light which can even aid the geological inquirer in conjecturing the extent to which it may have reached. All attempts hitherto made in all parts of the known world have failed in discovering any transition strata which shall form a bond of union between the Secondary and Tertiary formations; so that, with the exception of a very few doubtful species, and those of the lowest organization, there are not known to exist in any newer stratum the actual descendants of any of the inhabitants of the earth at the termination of the deposit of the Cretaceous rocks.

Nor is this all. The wide and marked distinction that exists between the general character and appearance of those groups of animals whose remains are found fossil in Secondary rocks and those of a more recent date, is scarcely less remarkable than the fact of the introduction of so many new species and genera.

So far from the inhabitants of the sea, during the deposit of the chalk, appearing to possess general analogies with those which in this part of the world next succeeded them, the contrast, on the other hand, is even more striking when we consider and compare the species amongst them whose habits were, to a certain extent, analogous;\* so that

\* This is a point which must not be lost sight of by the student who would comprehend fully the bearing of Zoological evidence on Geology. There are two ways of comparing fossils that occur in different strata. We may, for instance, take the different species in succession, determining how many agree with known species from other formations, or how many are still existing, and deciding what proportion of the whole number are in such a sense new. And as

we are not able to arrive at any real and satisfactory conclusions, owing to this wide departure from existing analogues.

And this difference, in all probability, was owing to very great changes that have taken place in the physical features of this part of the globe, affecting the habits of animals so completely, and extending through so long a period of time, as to call for an entirely new creation of species. I do not think it would be possible for us now to found any conclusions whatever as to the relative position of land and water in the northern hemisphere during the Secondary period, from the present contour of the land; but perhaps it is not too much to say, that such relative position, and even the configuration of the land, during the whole Tertiary period, differed comparatively little from that which now obtains

this method is, to a certain extent, founded on natural analogies, it may be expected to give true results; but it is not the way in which that kind of result, really valuable in Geology, can be determined; for it is founded on partial knowledge, and on limited and narrow views of nature. There is, however, another method, far more difficult to accomplish, rarely even attempted, and still more rarely successfully attempted, but without the application of which no sound general conclusion can be attained. I mean the comparison, not of species or genera, but of *groups*, and the result of a general and comprehensive view of the complete fauna of a district or a stratum, when the whole circumstances of the case have been fully considered with reference to all the known facts bearing upon the point.

Such a result as this is attained, when by the examination of the species themselves, and of their condition, relative abundance and relative development, a complete and definite notion has been acquired by the study of individual parts, and the knowledge of the philosophic and universal naturalist has been brought to bear upon the investigation. It is not every one who, for the amusement of a vacant hour, hammers out a fossil, and because he has not seen its like, supposes it to be a new species, and immediately describes it, who is really a naturalist, and still less is it for such an one to generalise in science. The generalisations of such persons, indeed, degrade science and render it contemptible, and since the discovery of a general law is the last and highest generalisation, it is almost ridiculous when such a discovery is assumed, or its existence denied, by those who do not even pretend to have studied, or who are utterly incapable of comprehending, the works of nature.



in a great part of Europe.\* Throughout the ancient rocks there is also commonly to be recognised some degree of mineral resemblance over a considerable tract, while such resemblance is almost entirely lost sight of in all European beds more recent than the chalk. One might, indeed, almost say, that the characteristic of Secondary and Palæozoic rocks was *Universality*, while that of the Tertiary is *Individuality*; for the former are rarely, and the latter most frequently, local; and the beds of the one have the same species of fossils characteristic of them throughout extensive districts, but the other rarely possess any such means of identification. The fossils also of contemporaneous Tertiary beds are very different from one another, so that it is chiefly by the relative proportion of those amongst them that have a modern aspect, or are identical with existing species, that any comparison can be made of the ages of distant Tertiary formations.

It is only of late years that the department of Geology professing to treat of strata newer than the chalk has assumed its due importance, and the reason of this it is not difficult to comprehend, for the Tertiary strata form a far less prominent group in Northern Europe than the rocks of older date, and were long considered as of unequal importance to these latter, and even as mere superficial deposits, scarcely worthy of being collected and described as forming a distinct system. But this relative predominance of older over newer deposits is reversed in the South of Europe, in some parts of Asia, and in America, where the newest strata are elevated

\* Although the relative position of the land cannot be traced so as to enable the Geologist to form any idea of the complete physical configuration of the earth's surface during the secondary period, it would appear that we may even now mark out lines of ancient cliff, against which the seas may have beaten before the deposit of the New red sandstone. Such a line of cliff is considered by Sir H. De la Beche to exist on the left bank of the Severn near Bristol.

far above the level of the sea, so that in the latter Continent they even form the flanks of the high mountains of the Cordilleras of the Andes.

It is well worthy of remark with regard to the Tertiary strata, that a very large proportion of them bear evident marks of having been formed in the vicinity of extensive tracts of land, and that in this respect they are strongly contrasted with many of the older rocks which appear to have been formed at the bottom of deep seas studded here and there with islands, such as those we now find in the tropical and southern oceans.

It is, I think, clear that after the termination of the Secondary period, and probably during a long interval of which we have no account, land had arisen from the deep waters, and the bottom of the sea, previously the receptacle of chalky mud, assumed by degrees the outline of continents not unlike those which are marked out by the mountain chains of Europe, Asia, and America. In such a manner alone, as it appears to me, can we account for the absence of all geological evidence of this period, which must have been considerable, and which, perhaps, was chiefly marked by disturbances producing elevation, and succeeded by denudation. But at a later period, when the deposition of the early Tertiary strata had already commenced, we may trace something of the former outline of the land in the present configuration of the country in many parts of the world, although in England the subsequent elevations by which the beds in the Isle of Wight appear to have been detached from those opposite to them on the main land have doubtless obscured and destroyed many such indications which may originally have existed. But however this be, it is certain that the rocks of the Tertiary period in Northern Europe are for the most part local deposits, and have been formed either

in lakes, rivers, or estuaries by deposition from fresh-water, or at the bottom of a sea not very far from land; so that various causes have come into operation, such as irregular depth, sudden and considerable alterations of depth, and many others, sufficient to modify greatly the conditions of animal life, and account for changes otherwise not to be explained in the nature of the fossils of contemporaneous beds not far removed in geographical position.\*

It arises from peculiarities such as these that the Tertiary strata do not for the most part admit of general descriptions applicable to extensive areas, but require that each group, as it is exhibited in a particular locality, should be the subject of special description with reference indeed to the other contemporaneous deposits, but still more with regard to the local circumstances accompanying its deposition. Thus it is that this department of Descriptive Geology differs essentially from those we have hitherto considered; so that a new method of classification becomes convenient, and instead of endeavouring to identify strata which are not continuous, by a comparison of their lithological characters, or even by the possession in each of identical species of fossils, it is necessary to examine and compare entire groups of species, not only with the similar groups in other formations, but with those existing animals and vegetables possessing similar habitats, and developed under analogous circumstances.

\* I would refer the reader who is interested in such considerations as these to the remarks of Sir Henry De la Beche, in his "Researches in Theoretical Geology," p. 190 *et seq.* It is there shown that a large surface of land round our own shores would be affected by a certain amount of elevation, and that there would be little comparative difference by a very considerably greater elevation. Nothing can indicate more clearly the permanence of the general outline of land for long periods, and under varying circumstances.

Geologists are indebted to Mr. Lyell for the first promulgation of a system of this kind, and for the elaborate care with which (assisted by M. Deshayes in the determination of species) he has fully and distinctly shown the applicability and truth of such a principle of classification. To Mr. Lyell's work on the *Principles of Geology* (1st Ed. vol. iii. chapter v.) I must refer the reader who would fully understand the nature and force of the arguments in support of his views on this subject. It will be sufficient here to mention, that the study of Conchology and the nature of those differences in their shelly habitations which correspond to true specific differences in molluscous animals, is still in a very imperfect state, and that we ought not, therefore, to depend with a confidence too implicit on the deductions arrived at by the Conchologist. Mr. Lyell has selected the shells of *Mollusca* as the principal fossils upon which to found his conclusions, because they are by far the most abundant organic remains discovered; but the conclusions thus arrived at must always be considered, to a certain extent, unsatisfactory, unless they are supported by other evidence arising from the comparison of the remains of animals of higher organization. It may, indeed, certainly admit of doubt, whether the actual determination of the proper position of a stratum in the series, can truly be learnt in all cases from the relative number of existing species of shells which it contains, many more considerations being requisite either to identify, or disprove the identity of, a bed of doubtful age.\*

\* "The relative approach which the shells may make to the living fauna, affords a useful and interesting term of comparison; but it is one feature only, and by no means the most prominent one, in the organic remains of successive periods." Lyell's *Elements*, first edition, p. 291.

Carrying out the principles which he adopted, and by means of which he arranged in their order the various strata of the Tertiary period, Mr. Lyell also proposed certain collective names founded on his method of subdivision. Of these names the first, EOCENE (ἑως dawn, and καινος, recent), was intended to include the older Tertiary strata, in which there appears, as it were, the first dawn of existing species. The next, MIOCENE (μειων, less) was so called, because in the beds to which this name was applied there were, although many more recent species than in the preceding group, *fewer* recent than extinct ones, while the name PLIOCENE (πλειων, more) was applied to the newer beds in which there was always a greater number of recent than extinct forms. It will be found convenient to retain these names, although without attaching any further meaning to them than that they express the older, middle, and newer Tertiary groups, and they enable us to speak of intermediate periods, such as older and newer Pliocene and the like, in the most convenient manner. It must, however, be clearly understood as an universal rule with regard to Tertiary deposits in localities where they cannot be clearly identified by any order of succession, that their relative age and position in the series must be determined by a special consideration of all the fossils discovered in them, and a careful comparison instituted not only between these and other fossils, but also with the animals and vegetables which still exist under circumstances as nearly as possible analogous.

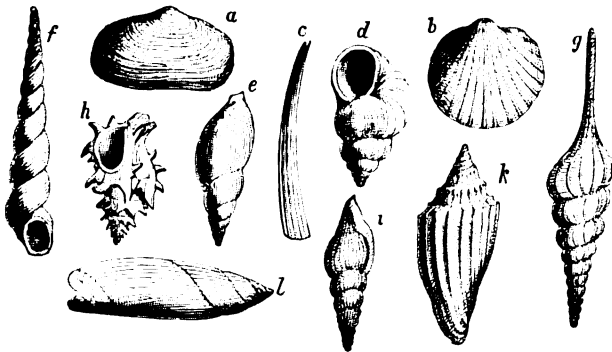
The method of arrangement which I propose to adopt in the following pages, in order to give the reader as definite an idea as possible of the Descriptive Geology of Tertiary formations, will not be exactly in accord-

ance with the tripartite division above described, because it has seemed to me hardly possible to communicate by such a method a sufficient notion of the actual and relative importance of Tertiary rocks in different parts of the world. I shall, therefore, commencing with our own country, first give a general view of the Tertiary strata as they are there developed, and then proceed to describe successively the older, middle, and newer European deposits of the whole period. I shall afterwards devote a Chapter to the Tertiary Geology of Asia, and another to that of the two Americas, and then consider, as forming a distinct group, those remarkable deposits not usually stratified themselves, but overlying all stratified rocks indifferently and unconformably, not so much because these diluvial and alluvial beds—the gravel and other similar accumulations—belong to a more recent period in the history of the world, but because they are cut off by a broad line of demarcation from the upper Tertiary beds, although, in many cases, contemporaneous and sometimes probably of older date.



## CHAPTER XXXV.

THE TERTIARY DEPOSITS OF THE BRITISH ISLES.—THE BASINS OF LONDON, HAMPSHIRE, AND THE ISLE OF WIGHT.—THE SUFFOLK AND NORFOLK CRAG.—THE NEWER TERTIARY BEDS IN THE VALLEY OF THE CLYDE.



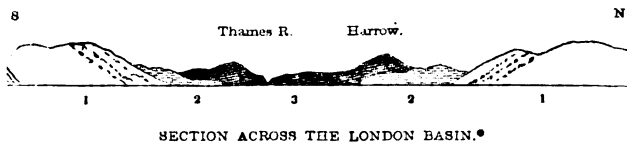
GROUP OF FOSSILS FROM THE LONDON CLAY.

- |   |                                      |
|---|--------------------------------------|
| a. <i>Sanguinolana compressa</i> . Sow. | g. <i>Fusus asper</i> . Sow.         |
| b. <i>Pectunculus scalaris</i> . Sow.   | h. <i>Murex tubifer</i> .            |
| c. <i>Dentalium striatum</i> . Sow.     | i. <i>Rostellaria lucida</i> . Sow.  |
| d. <i>Paludina lenta</i> . Sow.         | k. <i>Voluta luctator</i> . Sow.     |
| e. <i>Limnaea longicata</i> . Brong.    | l. <i>Ancillaria subulata</i> . Lam. |
| f. <i>Turritella imbricata</i> . Lam.   |                                      |

THE regularly deposited tertiary strata in England are found almost exclusively in the southern and eastern parts of the island, and they form two distinct groups, the lower and older consisting of a marine and chiefly argillaceous deposit of great extent, and often very considerable

thickness; but the other essentially littoral in its origin, and differing but little from the formations which we may imagine to be still in progress on the shores of the German Ocean. The former of these, the older group, is usually spoken of by Geologists as the "London Clay" while the latter is universally distinguished by the name of "Crag." In the valley of the Clyde in Scotland, and perhaps also elsewhere, there occur deposits of much newer date than the Crag, and these must be considered as belonging to the later Tertiary, and not to the recent period, notwithstanding the great general resemblance of the fossils found in them to the shells of marine animals still living in the neighbourhood.

#### I. THE LONDON CLAY.



The different strata which together compose what is called the London Clay deposit, are chiefly exhibited in basin-shaped depressions in the chalk, one of which occurs between the line of the North Downs and the chalk of Cambridgeshire, Hertfordshire and Suffolk, and another between the South Downs and the continuation of the same range into Dorsetshire, and the English Channel; the former is called the London and the latter the Hamp-

\* 3. London Clay.

2. Shingle beds at the bottom of the London Clay. (Plastic clay).

1. Chalk.



shire basin. There is also a third basin, in the Isle of Wight, remarkable for the presence of some fresh-water fossiliferous strata not found in the other part of the formation.

The beds forming the base of the London Clay sometimes rest on the chalk, and are often conformable to it; but there is clear proof of the latter bed having been long exposed in a consolidated state to the eroding action of waves and currents before the newer strata were superimposed. Deep indentations of the surface, into which sand and even fragments of chalk and flint have been rolled; the perforations of marine animals in the chalk also filled with fine sand, and the universal irregularity of the lower surface even when the dip is the same, afford abundant proofs of the lapse of a long interval between the completion of the one series and the commencement of the other.

The total thickness of the London Clay amounts to considerably more than a thousand feet. Its lower part consists of an indefinite number of beds of sand, shingle, clay, and loam, irregularly alternating with one another, and formerly looked upon as a distinct formation, and described under the name of the "Plastic Clay."\* The line of separation between these sandy beds and the true London Clay is, however, quite arbitrary; and Mr. Bowerbank has distinctly shown,† that a mass of clay two hundred feet thick, occurs in the lower part of the so-called Plastic clay formation in the vertical cliffs of Alum Bay in the Isle of Wight, and is loaded with London clay fossils,

\* This name was given from a supposed resemblance of the beds to the lower part of the contemporaneous series exhibited in the neighbourhood of Paris, where there is an important bed of clay, useful for brickmaking and pottery, and thence called *plastic*.

† Geol. Trans., 2nd Ser. vol. vi. p. 170.

while nearly eight hundred feet of variegated sands and marls intervene between this mass and the ordinary beds acknowledged to belong to the upper part of the formation. These sands and marls also are contemporaneous with other sands on the opposite coast of Hampshire, which are crowded with the characteristic fossils of the same newer beds.

The lower beds of the London Clay are distinctly laid open on the confines of the basins both of London and Hampshire, and the beds of shingle, of which they for the most part consist, are chiefly composed of chalk flints, and are apparently derived from the denudation of the chalk. These shingle beds have a decided appearance of littoral origin, and they occasionally, though rarely, alternate with fossiliferous bands ; but the absence of good coast sections renders it difficult to examine any extent of strata sufficient to justify general conclusions.

The middle and principal portion of the London Clay is generally of a blackish colour, and tough, but is often mixed with greenish-coloured earth and white sand, and occasionally encloses layers of oval or flattened masses of clayey limestone, called "septaria," which are traversed in various directions by cracks, filled completely with calcareous spar, and are particularly abundant in the neighbourhood of Harwich, where they are much used in the manufacture of "Parker's Cement."

Many parts of the London Clay contain, also, hard bands, either calcareous or siliceous, and sometimes fossiliferous, and the cliffs of Harwich occasionally include, besides the veins of septaria, other beds of true calcareous matter. The rocks of Bognor, near Chichester, and some similar beds in Alum Bay, are of the same period, and are composed of a dark grey calcareous sandstone, or siliceous

limestone, capped by a siliceous sandstone ; while at Bracklesham Bay, also on the coast of Sussex, there is a stratum of light green marly sand, occasionally hardened into a firm sandstone, which contains a great number of characteristic fossils, many of them identical with Paris Basin species, and not found elsewhere in England.\*

At the entrance of the Thames the London Clay extends on both sides of the river, and is admirably exhibited in the Isle of Sheppey, which consists entirely of this stratum. The cliffs on the north side of the island are upwards of two hundred feet high, and are cut down vertically by the action of the sea ; they have long been celebrated for the remarkable abundance and variety of the organic remains obtained from them, amongst which, perhaps, the most interesting are the fruits, berries, and woody seed-vessels of several hundred species of plants. From the same locality there have also been obtained the remains of upwards of fifty species of fish, and a considerable number of crustaceans and many other invertebrata ; besides some remarkable bones, which have been described by Professor Owen, and which indicate the former existence in this island of large serpents, and of such birds as prey upon small reptiles and mammalia. Many of these fossils, especially those of plants, are very difficult to preserve, owing to the great tendency of the iron pyrites (which enters largely into their composition), to effloresce and be destroyed by exposure to the atmosphere.

In the upper part of the London Clay in the Hampshire basin, and in the Isle of Wight, beds of fresh-water origin alternate with the marine beds, and are chiefly composed of calcareous marls of a green colour, and of siliceous sand

\* Magazine of Nat. Hist., vol. iv. New Series, p. 24. See also Conybeare and Phillips, p. 24 ; and Geol. Trans. 2nd Ser. vol. vi. p. 170.

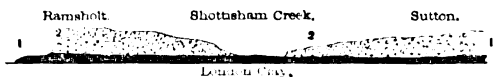
and limestones. These, together with marine strata interpolated with them, attain a considerable thickness, and are exposed in a vertical precipice at Headdon Hill, and at Hordwell Cliff on the opposite coast of Hampshire. A building-stone quarried at Binstead in the Isle of Wight also belongs to the same part of the series, and has been found to contain some interesting remains of mammalia.

Lastly, the *Bagshot sand*, a bed chiefly siliceous but sometimes marly, nearly devoid of organic remains, and offering little evidence of the period of its origin, has been supposed to belong to the London Clay formation, which it overlies conformably. It contains a few fossils apparently identical with those of the Paris basin, and the beds are found capping the Highgate and Hampstead hills near London, and several elevations in Surrey.

A bed of clay overlying a fossiliferous deposit of yellow and white sand observed at Kyson, near Woodbridge, in Suffolk, has of late attracted much attention among Geologists in consequence of the discovery in it of several mammalian remains. Both the sand and overlying clay are supposed to belong to the newest beds of the London Clay; but from the occurrence in it of the teeth of at least two species of fish, whose remains are also found in the overlying beds of the Red Crag, it is probable that we have here a passage bed connecting the lower with the upper Tertiaries of our island.\*

\* Lyell, *Elements of Geology*, second edition, vol. i. p. 344. Mr. Lyell elsewhere says, "As the clay at Kyson is covered by red crag at a short distance from the pits, and as I had seen clay of the same colour beneath the crag in the neighbouring cliffs of Bawdsey, and also at Felixstow and Harwich, containing *Septaria*, and as at Harwich the imbedded shells, fruits, and bones of *Turtle*, are such as characterise the London clay, I entertained no doubt that the Kyson formation belonged to the Eocene period." The subsequent discovery of other Eocene fossils places the Geological antiquity of the bed beyond question. *Annals of Nat. Hist.* vol. iv. p. 189, and Owen's *Brit. Fos. Mammalia*, p. 10.

## II. THE CRAG.



SECTION OF THE CRAG, NEAR IPSWICH.\*

I have already mentioned that the London Clay is overlaid by newer Tertiary deposits, to which the name Crag has been applied, and these, although not of any remarkable thickness, or traceable over an extensive area, are yet extremely interesting, for they are rich in organic remains, and represent, although in a debased form, the great series of the middle and upper Tertiaries, which in other parts of Europe occupy an important position among fossiliferous rocks.

The Crag consists of two distinct members, the Lower or Suffolk Crag, and the Upper, the Norwich or Mammaliferous Crag, of which the former is again subdivided into (1) the Coralline, and (2) the Red Crag, and is chiefly exhibited in the eastern part of the county of Suffolk. It is supposed to represent the Miocene or middle Tertiary period, and the Norwich crag the older Pliocene of Mr. Lyell.

It is to Mr. Charlesworth that Geologists are indebted for the correct determination of the relative ages of these deposits,† and for pointing out the distinct sections at Ramsholt, Tattingstone and other places, in which the Red Crag is seen to rest on the denuded surface of the older or

\* 2. Red Crag.

1. Coralline Crag.

† London and Edinb. Phil. Mag., August, 1835, p. 81.

coralline crag.\* There now remains no doubt of the order of superposition, or of the nature of the succession of the deposits in this part of England.

The *Coralline Crag* is of limited extent, ranging over an area about twenty miles in length and three or four in breadth, between the rivers Alde and Stour.† It varies in mineral composition, being sometimes entirely made up of fragments of shells and zoophytes, but occasionally, as at Tattingstone in Suffolk, consisting of a greenish marl with a few stony beds sometimes even quarried as a building stone. The total thickness of the bed rarely amounts to twenty feet, although in some particular localities (as at Sudbury, near Orford) it is much thicker.

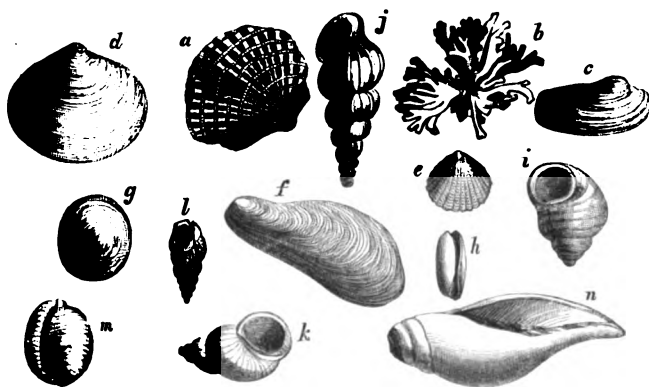
The fossils most abundant and characteristic of this lower or coralline crag are chiefly the remains of zoophytes, referrible, for the most part, to species unknown in a living state. These are incredibly abundant, and are found associated with fragments of echinodermata and shells, few of them agreeing with recent forms.

The *Red Crag* is distinguished by its deep ferruginous colour, and contrasts strongly in this respect with the white colour of the Coralline Crag. Its total thickness amounts to about forty feet, but is often much less, and it appears to have been deposited under circumstances somewhat different from those which obtained in the

\* I believe I am correct in asserting, that Geologists are also indebted to Mr. Charlesworth for the determination of the age of these deposits by the comparison of their fossils, and the application of what has been called the percentage test. At least I so understand the following passage from the abstract of a paper read by Mr. Charlesworth in May, 1835: "The author then enters into an inquiry respecting the relative age of the red and coralline crag; and *from the difference in their zoological contents*, he concludes that the two beds were deposited under different conditions, *at different periods*." *Vide* Proceedings of Geol. Soc. of London, vol. ii. p. 196. See also Mag. of Nat. Hist. new ser., vol. iii. p. 323.

† Lyell's Elements of Geology, second edit., vol. i. p. 318.

earlier period. Its fossils are numerous and sufficiently characteristic, many of them differing widely from ex-



GROUP OF FOSSILS FROM THE CRAG FORMATION.

- |  |                                      |
|--|--------------------------------------|
| a. <i>Fascicularia aurantium.</i> M. Edw | k. <i>Bulla cylindracea.</i> Montf.  |
| b. <i>Tubulipora.</i> (?)                | l. <i>Littorina littorea.</i> Wood   |
| c. <i>Saxicava rugosa.</i> Lam           | f. <i>Scalaria similis.</i> Sow      |
| d. <i>Tellina crassa.</i> Flem.          | k. <i>Paludina unicolor.</i> Swains. |
| e. <i>Venericardia scalaris.</i> Sow     | i. <i>Nassa elegans.</i> Sow.        |
| f. <i>Modiola.</i> (?)                   | m. <i>Cypræa avellana.</i> Sow.      |
| g. <i>Patella asqualis.</i> Sow.         | n. <i>Voluta lamberti.</i> Sow.      |

isting species, and some of them, as *Fusus contrarius*, and a few species of *Murex* and *Buccinum*, quite peculiar to the formation. Others again, as the *Astarte*, are common both in this and in the Coralline Crag.

The *Mammaliferous* or *Norwich Crag*, which is decidedly of more recent origin than the Red Crag, is chiefly composed of shelly beds of sand and loam, well exhibited in the neighbourhood of Norwich, and also at Southwold, in Suffolk. This formation is not so entirely marine as the lower beds already described, but appears rather to have taken place at the mouth of a river, as many as twenty species of land and fresh-

water shells, together with numerous mammalian remains, being distributed through it. Mr. Charlesworth has named this the *Mammaliferous Crag*, and it well deserves the name, as presenting the first instance in the ascending order of formations in England, where numerous mammalian remains occur embedded in a regular stratum. Overlying the Norwich or Mammaliferous Crag, other strata succeed, which are decidedly lacustrine, and which contain also the remains of mammalia, and with these the series of Tertiary stratified deposits in England is brought to a final close. The lacustrine strata, indeed, may be considered to belong to a period immediately antecedent to the recent period, and during or subsequent to their deposition and before the commencement of the present condition of things, there must have occurred many considerable changes of the surface, which have resulted in the covering up a great portion of Northern Europe with superficial beds of rolled pebbles and gravel.

The existence of the Crag in England is not absolutely confined to Norfolk and Suffolk, although it is there chiefly that the beds are developed. In Yorkshire, near Bridlington, there are certain deposits of sand and clay containing marine shells, of which thirty or forty species have been determined, and most of them are identical with Norwich Crag fossils.

At several points in the valley of the Thames, and on the banks of the Stour and Medway, there are found fresh-water deposits, consisting of from twenty to sixty feet of loam, sand, and gravel. In other similar but marine deposits, fossils of the same modern period are also sufficiently abundant, almost all the species resembling those inhabiting the neighbouring seas, but having a more arctic form, which the investigations of



Professor E. Forbes would show to be owing to the deposit having taken place at a greater depth of water than that at which the species are now found. These latter fresh-water and marine deposits are considered to belong to the Newest Pliocene or Pleistocene period of Mr. Lyell.

The tertiary formations of Scotland are not very numerous, and belong entirely to the most recent Tertiary period; that which occurs in the valley of the Clyde, and which has been minutely described by Mr. Smith, of Jordanhill, is, perhaps, the most interesting and important, as it is supposed to represent two distinct epochs: the one being identical with the Pliocene of Mr. Lyell, and including the so-called "*Till*," and the other yet more nearly approaching the recent period, and exhibiting an almost perfect identity when the fossils found in it are compared with the recent fauna of the neighbourhood.

The lower part of the Till seems to consist of a stiff unstratified clay and gravel, confusedly mixed with angular fragments and water-worn masses, and containing, though rarely, the bones of elephants, and also a few shells. In other places the till appears to rest upon a non-fossiliferous series, consisting of beds of sand, gravel, and clay, apparently of marine origin.

Overlying these lower beds, a number of other strata occur, which are not known to contain fossils, and to these a remarkable deposit succeeds, in which the remains of ancient forests are observable. The whole series is covered up by other strata of marine origin, containing fossils in extreme abundance, the fossils consisting chiefly of fragments of shells referrible to species still common in the neighbourhood, associated with others apparently exhibiting a more arctic type.

Of these beds the submarine forests (which are also met with in many parts of the south-western and western coast of England, and which always appear to preserve the same general features) do not seem to require any very detailed description. The most extensive of them is that of the basin of the Tay, which has been observed in detached portions for about ten miles on the south side of that river, and also on the opposite shore, and extends through the whole of Strathearn. "It may be described as a bed of peat, containing stumps of trees in the attitude of growth, resting upon beds apparently of marine origin, and covered by others *containing marine shells*."\* In this stratum of peat moss, many roots of large trees are to be found, principally alders and birch, at about thirteen feet from each other, and perfectly upright, with their ramifications extended among the moss, and some of the smaller fibres penetrating the clay below.

The overlying marine beds correspond to those which have received the name of "raised beaches," and they offer as distinct evidence of recent elevation as the submarine forests do of depression.

\* J. Smith, Esq., of Jordanhill, "On the last Changes in the relative Levels of the Land and Sea in the British Islands." Mem. of Wern. Nat. Hist. Soc. vol. viii. p. 29.

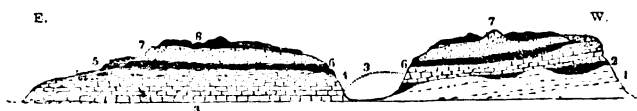
## CHAPTER XXXVI.

## THE OLDER TERTIARY OR "EOCENE" DEPOSITS ON THE CONTINENT OF EUROPE.

THE principal Eocene deposits on the Continent of Europe are (1), the Paris Basin, the beds composing which are chiefly of marine origin, or deposited in an estuary, but which include also some very interesting fresh-water deposits; (2) a marine deposit resembling the London clay, and found in the neighbourhood of Brussels; and (3) lacustrine formations of the same date in Auvergne and Cantal, in central France. Besides these there are some small patches of contemporaneous strata in the west of France, others at Aix in Provence, and others again in the north of Italy.

## I. THE PARIS BASIN.

The Geological position of the city of Paris resembles in some measure that of London, each being situated upon an extensive and important group of Tertiary strata which occupies a depression or basin in the underlying chalk. The nature of these two deposits is, however, totally different, the deposit being characterised in our own island by great accumulations of argillaceous matter, which form the London clay, while in the neighbourhood of Paris there is a varied series of limestones and marls,



SECTION ON THE BANKS OF THE SEINE FROM POISSY TO MANTES.\*

alternating with important bands of gypsum and siliceous matter.

The depression in the chalk which is filled up by these strata in France, is nearly one hundred and eighty miles in its greatest length, and about half that in breadth. The surface of the chalk is usually covered by broken and rolled flints, often cemented by a siliceous sand into a kind of breccia; and these flints appear to mark the action of the sea upon reefs of chalk before the commencement of the Tertiary epoch.

The first of the regularly stratified deposits of the Paris basin taken in ascending order, and, therefore, the oldest member of the group, is overlaid by two very distinct but contemporaneous beds; and it appears that, in different parts of the area above described, two formations must have been going on at the same time, one of them marine, in a portion of the basin exposed to the action of marine currents, and the other partly fresh-water, as if deposited at the mouth of a great river, and partly of estuary origin and from brackish water. Each of the beds thus in process of deposition, we find sometimes dis-

- \* 8. Upper marine sands.      7. Upper fresh-water sands.
- 6. Green marls.
- 5. Gypsum.
- 4. Calcaire siliceux.      3. Calcaire grossier.
- 2. Plastic clay.
- 1. Chalk.

tinctly exhibited to the exclusion of the other, but occasionally alternating with it in various parts of the basin.

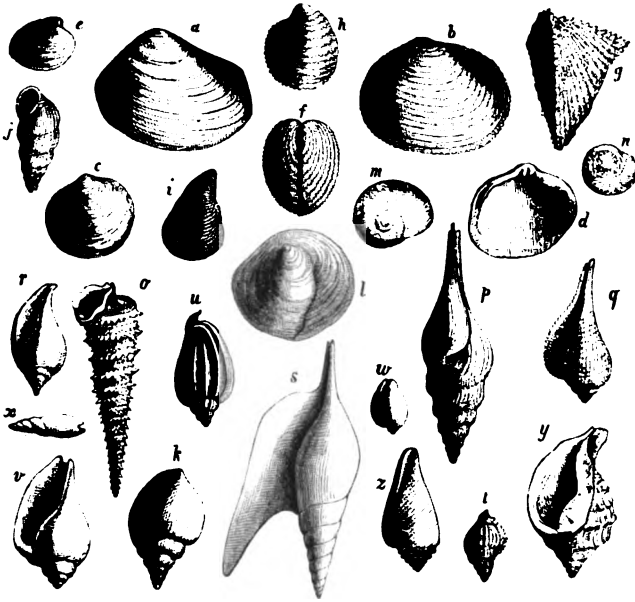
The nature of the peculiar arrangement of these beds will, perhaps, be best understood by referring to the annexed diagram. The base of the system is usually found to consist of a fresh-water deposit of clay and lignite [marked (2) in the diagram] often reposing in hollows, and containing rolled flints from the underlying chalk. To this succeeds either a marine limestone [the *calcaire grossier*, (3)], or a fresh-water limestone [*calcaire siliceux*, (4)].

The fresh-water deposit of clay (2), including several bands of lignite, and many fossil shells, covers an extensive area of the chalk, and consists for the most part of excellent potter's clay, which is sometimes used in the manufacture of fine porcelain, and is hence called *Plastic Clay*. This clay is of a red colour, contains a little iron, a small proportion of silex, and fragments of chalk and gypsum; its thickness is rarely so much as fifty feet, and the upper beds are sometimes sandy. It includes a considerable quantity of lignite either in thin layers regularly stratified, or distributed in compact masses of a texture so dense as to be susceptible of polish. Pyrites are occasionally present in the lignite, and nodules of amber and other resinous substances are also disseminated through it.\* Plastic clay is, however, not by any means confined to a fixed place in the series, as it alternates with the marine limestone, and is sometimes repeated in the middle or upper part of that formation.

2. The marine limestone, or *calcaire grossier*, is a coarse limestone often passing into sand, and occupying the

\* Ossements Fossiles, fourth edit. vol. iv. p. 46.

northern part of the Paris Basin. It is interesting as being by far the richest of all the older Tertiary beds in fossil shells, upwards of four hundred species of which



GROUP OF SHELLS FROM THE PARIS BASIN.

- |                                   |                                       |
|-----------------------------------|---------------------------------------|
| a. <i>Crassatella tumida</i> .    | n. <i>Bifrontia laudensis</i> , Desh. |
| b. <i>Corbis pectunculus</i> .    | o. <i>Cerithium tricarinatum</i> .    |
| c. <i>Lucina concentrica</i> .    | p. <i>Pleurotoma transversaria</i> .  |
| d. <i>Cyrena depressa</i> .       | q. <i>Pyrula nexilis</i> .            |
| e. <i>Venus turgidula</i> .       | r. <i>Fusus bulbiformis</i> .         |
| f. <i>Venericardia coravium</i> . | s. <i>Rostellaria columbella</i> .    |
| g. <i>Cardium aviculare</i> .     | t. <i>Strombus ornatus</i> .          |
| h. <i>Chama lamellosa</i> .       | u. <i>Harpa mutica</i> .              |
| i. <i>Pileopsis cornucopiae</i> . | v. <i>Buccinum stromboides</i> .      |
| j. <i>Cyclostoma mumia</i> .      | w. <i>Marginella ovulata</i> .        |
| k. <i>Ampullaria acuminata</i> .  | x. <i>Oliva nitidula</i> .            |
| l. <i>Nertina conoidea</i> .      | y. <i>Cassidaria carinata</i> .       |
| m. <i>Natica cepaeos</i> .        | z. <i>Conus diversiformis</i> .       |

have been procured from it in a single locality at Grignon near Paris. The shells are embedded in a calcareous

sand, itself chiefly made up of fragments of shells, but in which individuals are perfectly preserved. Among the fossils which are the most perfectly preserved, and the most abundant, may be mentioned those of the genus *Cerithium*, of which alone nearly one hundred and forty species have been determined; and as the living congeners are usually found in estuaries and in brackish water, we have thus an additional proof, if any were wanted, of the partial presence of land at the time of this marine deposit.

I have figured in the preceding page a group of some of the more characteristic shells chiefly from this part of the formation, and most of them, indeed, from Grignon itself.

The calcaire grossier consists (besides the fossiliferous sand) of argillaceous and calcareous marls, arranged in very constant order, and alternating with hard limestones. Among the different bands of these latter there are found some in which the fossils, called *Nummulites*, are exceedingly common, while another bed, used as a building stone, is almost entirely made up of myriads of microscopic shells. The Nummulite limestone is principally characteristic of the lower beds, and the Miliolite limestone (as the other bed is denominated, from the resemblance of its small microscopic shells to millet seed) is more common in the middle beds, in which are also found most of the characteristic fossils of the group. The upper beds are, however, remarkable for containing the greater number of the different species of *Cerithium*.

3. The *calcaire siliceux*, or fresh-water limestone, is a remarkable bed resembling a precipitate from the waters of mineral springs, and it is principally developed in a part of the Paris Basin quite distinct from that in which the calcaire grossier abounds, although the two beds

sometimes alternate. It contains but few organic remains, but is full of small empty cavities. Its mineral condition is singular, and in some parts a kind of stone is obtained from it which is used for millstones, and might almost be considered as the siliceous skeleton of the calcaire siliceux, the calcareous part being absent: as if the bed after deposition had been exposed to the action of some mineral acid capable of dissolving carbonate of lime.

The second group in the general series of Paris Basin rocks consists of white and green marls, with a considerable quantity of gypsum, the latter being chiefly developed in the centre of the Basin. The upper members both of the calcaire grossier and siliceux alternate occasionally with these marls; but the latter form, on the whole, a distinct overlying group of fresh-water origin, and contain land and fluviatile shells, fragments of wood, and great numbers of the bones of fresh-water fish, of crocodiles and other reptiles, of birds, and even of quadrupeds, the latter being usually isolated, and often entire. The gypsum beds having been extensively quarried for the manufacture of "Plaster of Paris" (obtained by burning the gypsum) they have yielded a multitude of these mammalian remains, which formed the base of the great discoveries of Cuvier, so that the investigation of them by that anatomist may even be considered to have laid the foundation of the science of Palæontology, so far as it is dependent on sound principles of analogy. It is chiefly the lower part of the gypsum which formed this great charnel-house of extinct quadrupeds; but the uppermost strata, composed of thick beds of marl either calcareous or argillaceous, are also worthy of notice, and contain numerous silicified trunks of palm trees.

Thirdly and lastly, we find another group more modern



than the gypsum of the Paris Basin, but still belonging to the Eocene period. This group consists of two formations, one marine, and the other fresh-water, and both of them attain considerable thickness, being composed of marls, micaceous and quartzose sands, and layers of flint. A thin bed of oysters separates the gypsum from the overlying sands of marine origin; but these oysters do not appear to have grown on the spot, but rather to have been swept away by marine currents from a bed at no very great distance. The summits of many of the hills in the Paris Basin consist of the upper marine series, which appears subordinate to the fresh-water marls and the siliceous nodules of fresh-water origin.

The whole of this extensive and important group of Tertiary formations is referred to the same great Geological period, and must be considered to represent, as it is contemporaneous with, the equally extensive, but far less varied group of strata, called the London clay, in the south-east of England. The Paris beds appear, however, to have been deposited in an open gulf, in which several rivers were emptying themselves, and there is distinct evidence that many alterations of level must have taken place between the commencement and conclusion of the whole series of strata.

## II. THE BASIN OF THE NETHERLANDS.

THE Tertiary strata, which may be thus denominated, and upon which the city of Brussels is built, are chiefly developed in the provinces of South Brabant and Limburg. The neighbourhood of Laeken, in the former province, and Kleijn-Spauwen and Housselt, near Maestricht, in the latter, are especially remarkable for their fossil shells, but

many species are also sufficiently common in other localities.

The general character of the strata in this basin is that of different sandy beds, containing more or less iron, alternating with, and overlying a series of badly-developed marls and limestones. The whole sequence is rarely exhibited in the same locality, but the total thickness of the deposits is not considerable.

The argillaceous marls which form the base of these deposits, contain numerous London clay fossils, and are found chiefly in the northern and western parts of the basin. In the east of Flanders, where they attain their greatest thickness, they consist of horizontal layers of clay, of a blue or black colour, which are impermeable to water, and include, like the similar beds in the London Basin, those peculiar oval calcareous masses called *Septaria*. Near Brussels this clay is also found, but it there becomes more calcareous, and even passes into a fossiliferous calcareous sand of a greyish or yellowish colour and fine grain. This part is sufficiently hard to be used as a building-stone, and contains enough calcareous matter to be worth burning for lime. The upper beds are chiefly sandy and ferruginous, and often friable, with occasional hard nodules. Near Louvain they pass into thick beds of reddish or brown sandstone, the proportion of iron being sometimes only sufficient to serve as colouring matter, but so abundant occasionally, when the beds are thinner, as to be worth working as an ore.

### III. THE FRESH-WATER BASINS OF CENTRAL FRANCE.

The central portion of France is remarkable for exhibiting an extensive granitic platform, through which, in

several places, volcanic eruptions have taken place, at a comparatively modern period, and in which there also occur several basins, containing fresh-water deposits of Tertiary origin. Some of these are referrible to the older or Eocene period, and they appear to be the remains of ancient lakes, like those of Switzerland, which have been long filled up by beds of marl and sand, and various siliceous and calcareous rocks.\*

The most northerly of these groups is that of Auvergne, and it extends for a considerable distance in a north and south direction, with an average breadth of about twenty miles. It includes a number of beds of sandstone, marl, and limestone, the marl being often gypseous, and the limestone oolitic, or pisolitic, and not unfrequently formed to a great extent of *indusia* or cases, formerly accumulated round the bodies of small worms, such as the caddis-worm, the larva of the may-fly, &c.

These different beds are found to alternate in some places with each other, but the sandy strata and conglomerates may on the whole be considered to form a littoral and overlying group, the limestones being the lowest, and the green marls perhaps forming a central group contemporaneous with some portion of the sands. Volcanic tuffs and lava occasionally make their appearance, interstratified with the lacustrine strata, and indicating the date of the volcanic eruptions in this district.

A fresh-water deposit, like that of Auvergne, is also found near the town of Le Puy in Velay, and another near Aurillac in Cantal. The former is exceedingly similar in all respects to the Auvergne deposit; but the latter is remarkable for the immense abundance of silex associated with the calcareous marls and limestone. The limestone also

\* Lyell's Elements of Geology, second edit. vol. i. p. 360.

singularly resembles the upper beds of the chalk formation, both in mineral character, and in the presence of layers of flint in nodules. The silix, is, however, the most remarkable character of these beds, being not only loaded with, but almost composed of, the minute cases of microscopic animalcules; and the presence of so large a quantity of this mineral, was probably owing to volcanic agency employed in the formation of the deposits.\*

Of the remaining deposits of the Eocene period in Europe, it is not necessary that I should give any detailed account. The small basin of the Cotentin, in the department of La Manche, consists chiefly of a coarse limestone, not unlike the *calcaire grossier* of the Paris Basin, and contains identical species of fossil shells.

Near Rennes, other similar basins of small size in the older rocks are filled up by beds of the same date, which have been described in detail by M. Desnoyers.† The Tertiary strata of Aix, in Provence, are the only ones that require special notice.

These beds, which have been described by Messrs. Lyell and Murchison, consist for the most part of lacustrine strata of marl and marly limestone, associated with gritstone and compact limestone of fresh-water origin, closely resembling the limestones of the old rocks. In these beds, a number of species of insects have been found in thin grey calcareous marls, occurring in gypsum quarries, near the town of Aix. The fossils (which include also numerous specimens of *cyclas*, and innumerable remains of the small

\* It is well known that the hot springs in Iceland and other countries contain a considerable quantity of silix in solution, and it has lately been affirmed, that steam at a high temperature is capable of dissolving quartz rock, without the aid of alkaline or other flux. Lyell's Elements, second edit. vol. i. p. 381.

† Mem. de la Soc. d'Hist. Nat. de Paris, 1825.

crustacean called *cypriis*) are arranged in layers, one of which, containing the insects, is about two inches thick ; another, abounding with the remains of fish, is a little thicker ; while others, again, containing the leaves of land-plants, are much thicker. The insects hitherto discovered are of European types, and not of those tribes whose habits are aquatic.\*

Overlying these fresh-water beds there occurs a small deposit of marine sand, in which are found large oyster-shells. All the beds of the series are inclined at a considerable angle to the horizon in the valley and near Aix, but are horizontal at the top of the adjoining hill.†

On the southern flank of the Alps, and north of the town of Vicenza in Lombardy, a bed of limestone occurs containing shells referred to Eocene species, and several fossils obtained from basaltic tuffs associated with this limestone are identical with species characteristic of the Paris basin. These are chiefly from Ronca and some neighbouring localities, but at Monte Bolca, under similar circumstances, the fossil remains of fishes have been met with in extraordinary abundance in marly limestones, interstratified with thick beds of compact limestone, and the whole series is overlaid by tabular basalt.

The recent researches of Lieut. Spratt, R.N., would appear to show that similar fresh-water deposits of contemporaneous origin exist in the southern part of the Gulf of Smyrna, and are continued into several of the neighbouring islands. It would appear that a great fresh-water lake must have existed, during the Eocene period, in the eastern part of the Grecian Archipelago, where now there is deep sea.

\* Lyell's Principles of Geology, third edition, vol. iv. p. 155.

† Edin. Phil. Journ. for 1829, vol. xxi. p. 287.

## CHAPTER XXXVII.

## THE MIDDLE TERTIARY, OR "MIOCENE" DEPOSITS IN EUROPE.

THE middle Tertiary period, although only represented in British Geology by a portion of the "Crag" formation, is marked in other parts of Europe by the development of a most important group of strata, exceeding in thickness and covering a much larger area than any of the older Tertiary deposits. The most important of these Miocene beds occupy a portion of the west of France, and fill up nearly the whole of the great valley of Switzerland, extending from the lake of Geneva to the frontier of Germany, and they may thence be traced still further to the east, following the course and partly occupying the valley of the Danube. Along this line they are found expanded from point to point, forming the basins of Vienna and of Styria, and passing into the plains of Hungary; then diverging northwards, they may be followed into Poland and Russia, and in some parts of the former country they have been extensively worked for rock salt, which they contain in great abundance in certain localities. Contemporaneous deposits have also been found near Turin in North Italy and in the valley of the Bormida, where the Apennines branch off from the Alps.

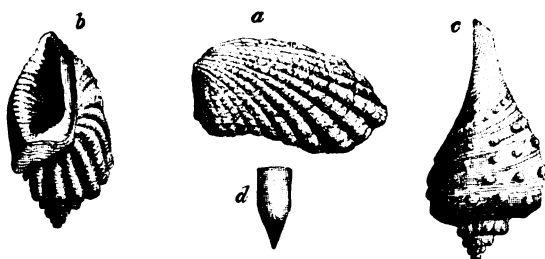
The basins of the Loire and the Garonne, and the neigh-

bourhood of Montpellier, are the principal districts in France where the beds of this period are to be found. The beds of the former (the basin of the Loire) are chiefly developed near the city of Tours, and in the 'Touraine' district, where they consist for the most part of broken shells, and greatly resemble the shelly portion of the British 'Crag.' They sometimes, however, form a building stone, the comminuted shells being mixed with sand and gravel, and cemented by the infiltration of calcareous matter. The remains of quadrupeds are occasionally found associated with the shells, and they belong to species quite distinct from those which characterise the Paris basin. The superposition of these Miocene strata upon the true Eocene beds with Paris basin fossils, is fully made out in the Cotentin, and elsewhere.

A considerable tract of country, extending from the mouth of the river Garonne towards the south-east, is covered up with Tertiary deposits of this middle period, which have been principally studied in the environs of Bordeaux, Dax, and one or two other towns. The beds consist of incoherent quartzose sand mixed with calcareous matter, and they contain a great number of fluviatile shells associated with others of marine origin. As in the basin of the Loire, these fossiliferous beds rest upon strata of older date, from which they are separated by the interposition of a considerable mass of fresh-water limestone. From the basin of the Garonne there would appear to exist a series of Miocene Tertiary beds, traceable at intervals as far as Montpellier, and there overlaid by other beds of newer date, which pass upwards into the older Pliocene deposits.

In the annexed engraving some of the more characteristic shells from the marine beds of the Loire and Garonne

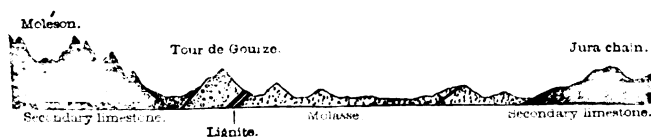
are represented. The condition of these fossils is generally good.



GROUP OF FOSSILS FROM THE BASIN OF THE GARONNE.

- a. *Cardita*.
- b. *Cancellaria*.
- c. *Pyrula*.
- d. *Vaginula daudini*

On the southern flanks of the Alps, near Turin, there appears to be unquestionable evidence that a greenish sand, immediately in contact with the older rocks, belongs to the middle rather than to any newer Tertiary deposit. The bed alluded to is inclined at a high angle to the horizon; it is clearly of more ancient origin than the mass of the Tertiaries on the southern side of the great Alpine chain, and fossil shells are found in it different from those of the sub-Apennines, and more resembling the Touraine species.



SECTION ACROSS THE VALLEY OF SWITZERLAND.

Switzerland exhibits, in the great valley extending throughout its length between the Alps and the Jura



chain, a very extensive series of Tertiary sandstones referrible to the period which we are now considering.\* In the southern part of this deposit, between the lakes of Geneva and Lucerne, these beds consist of a coarse conglomerate called 'Nagelfluhe,' gradually passing into a finer sandstone (the 'Molasse'), which is usually soft and incoherent, but sometimes sufficiently hard to be used as a building stone. Both these beds, of which the latter is by very much the thicker and more predominant, are either entirely without fossils, or at least contain them very rarely; but various beds of marl and lignite are distributed irregularly through the molasse, and these are evidently of fresh-water origin, and contain the remains of fresh-water shells.

In the north, and beyond the lake of Lucerne, the molasse has been found, by Prof. Studer, of Berne, to contain marine shells and other fossils, so that it is not unlikely that the whole formation may have been deposited in an estuary open towards the north-east. We shall see afterwards that the occurrence of Tertiary beds of newer date, on the banks of the lake of Constance and in the valley of the Rhine, offers sufficient proof of great changes of level having taken place in this part of Europe since the Miocene period, and it is not unlikely that a considerable portion of the elevation of the Alpine chain has been effected since the molasse was deposited. The thickness of the molasse is very great, and it forms hills which attain an altitude of nearly three thousand feet above the level of the lake of Geneva.

The Tertiaries of the great valley of Switzerland are repeated in the valleys of the Jura, where they contain fossiliferous beds of fresh-water origin, the fossils being identi-

\* Cambridge Phil. Trans. vol. vii. p. 141.

cal in species with some of those in Miocene beds in other parts of Europe. They are also found, although in a somewhat different form, in the valley of the Rhine, between Switzerland and the Taunus range of hills,\* and more especially in the Duchy of Darmstadt, and in some parts of Rhenish Bavaria, where the remains of quadrupeds have been occasionally found associated with numerous shells of molluscous animals. The animal remains entombed in these strata of sand and marl are exceedingly interesting, and they exhibit a passage from the fauna of the Eocene period to those species found in newer formations, and, therefore, more nearly resembling the animals of our own time. We find, for instance, fragments of bone indicating the existence of species now extinct, but common in the gypsum beds of the Paris Basin, and together with these, the bones of Rhinoceros, Elephant, and Hippopotamus, and the remains of an entirely new genus (*Dinotherium*) peculiar to the formation, and exhibiting some striking anomalies of structure.

But the main development of the Miocene deposits in Europe is to be sought for rather in the centre and east of the continent than in any of those districts we have yet considered. Most of the beds of this period in central Europe are of marine origin, and lie in strata nearly

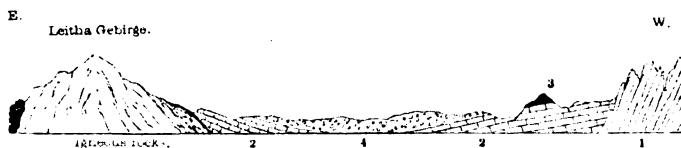
\* The Rhine, which pursues a somewhat sinuous course to the north through a broad alluvial valley, from the point at which it leaves Switzerland, to Mayence, where it receives its important tributary the Main, then turns suddenly to the west, deflected by the Taunus hills, and at Bingen enters that magnificent gorge, to the picturesque scenery of which the river owes so much of its celebrity. The Taunus chain is only separated from the Hunsrück by the deep and narrow cleft through which the Rhine makes its way, and the hilly country is continued as far as Bonn, and terminates with the singular volcanic district of the Siebengebirge. Afterwards the alluvial plain through which the river takes its course, is unvaried by any picturesque scenery. The Rhine valley is thus divided into two distinct basins, of which the upper one (between Mayence and Switzerland) contains, at intervals, beds of the Miocene period.

horizontal; they are also of vast thickness, and are found to possess on the whole a slight easterly dip.

Commencing with the marine part of the Swiss molasse near the lake of Lucerne, a series of deposits of the same kind may be traced, occupying a very extensive area, extending towards the north-east, and in that direction they are covered up by newer beds in the great alluvial plain of Bavaria, through which the numerous tributaries of the Danube make their way from the Tyrolese Alps. Portions, however, are traceable at intervals, and they are again extensively developed near the town of Passau, both on the right and left bank of the Iser, where that magnificent river empties itself into the Danube.\* Past the Böhmerwald, where the Danube again expands as it enters Austria, there are two principal deposits of the Miocene Tertiaries, one of them in the north forming the Basin of Vienna, and the other in the south, which is much more considerable, and may be called the Basin of Styria. Both these stretch towards the east, and are chiefly separated by the alluvial plain of the Danube, but they again approach between Pesth and Chemnitz, in the centre of Hungary, and may thence be traced to the Carpathian chain. Thus along the whole course of the Danube, as far as the Turkish frontier, there appears to have been a succession of strata deposited during the middle Tertiary period, the deposition having probably taken place in an open sea, which may have communicated with the Black

\* The valley of the Danube, like that of the Rhine, makes its way through noble and picturesque gorges, intersecting both altered and igneous rocks in its progress. One of these gorges, seen between the towns of Passau and Linz, is much grander in the wild and savage character of its mountain scenery than the corresponding part of the Rhine, and perhaps indeed the chief attraction in the Danube scenery, and that which most distinguishes it throughout from its great rival in western Europe, is the character of immensity that is so predominant. This far more than makes up for any deficiency it may possess in some of the milder and calmer beauties, and the artificial adjuncts of the Rhine.

Sea on the east, and the Adriatic on the south, before the final changes of elevation took place in this part of the continent of Europe.



SECTION ACROSS THE TERTIARY BASIN OF VIENNA.\*

The basins of Vienna and Styria, like most of the other members of the great Miocene deposit, consist chiefly of a series of conglomerates, sandstones, and marls, associated with beds of lignite, but these are overlaid by coralline limestones of considerable thickness, which are sometimes concretionary.†

Near Vienna the lower beds are ill exposed, and the coralline limestone is covered up by calcareous marls and limestones having an oolitic structure. In Styria, the overlying beds alternate with volcanic ashes and other matter, apparently ejected from the now extinct craters on the confines of Hungary. All the three groups contain the bones of mammalia and molluscan remains in great abundance, and notwithstanding the great thickness and extent of the different beds (the coralline limestone alone being exposed in cliffs which exhibit four hundred feet of vertical thickness), there is no reason to doubt that the whole must be referred to the same period, being probably contemporaneous with the red and coralline Crag on the coast of Suffolk.

- \* 4. Gravel and Loess.
- 3. Fresh-water limestone.
- 2. Leitha kalk.
- 1. Alpine limestone (Secondary).

† Geol. Trans. 2nd Ser. vol. iii. p. 382.

The Miocene beds of Austria are cut off by the mountains of the Carpathian chain, but are again repeated to the North of these mountains by several patches on the left bank of the Vistula below Cracow, and in the provinces of Galicia, Volhynia, and Podolia. In these latter provinces, the great masses of gypsum and rock salt, which have been long celebrated, are supposed to belong to the period we are now considering.\*

It seems probable, judging from the evidence of fossils, that a series of sandy but fossiliferous limestones, interstratified with clay, and described by Mr. Sharpe as occupying a somewhat important place among the strata in the neighbourhood of Lisbon, must be referred to the Miocene period. These beds are well exhibited on both banks of the Tagus, but they have been much disturbed since their deposition by very extensive dislocations, so that some of the limestones belonging to the series dip at an angle of  $80^{\circ}$  *towards* the old rocks, having been elevated through an angle greater than a right angle, and, therefore, turned upside down.†

Other beds in the South of Spain appear to be contem-

\* The most remarkable of the salt deposits associated with these marls and gypsum beds is that of Wieliczka, and it covers a surface about 3000 yards in length, 1200 in breadth, and nearly 300 in thickness. Three subdivisions may be remarked in it: in the lower beds the salt is lamellar in its structure and very pure, being only accompanied with a little sulphur; in the overlying bed the salt is compact and tolerably pure, but is associated with fragments of shells and small beds of lignite, while in the upper part of the formation the salt exhibits a green colour, and contains in it a small quantity of gas, causing it to decrepitate when being dissolved. The prevailing rock in which the salt occurs is an argillaceous marl of a bluish grey or reddish colour, resting on a sandstone or conglomerate.—*D'Aubuisson par Burat*, vol. ii. p. 560.

I ought not to omit to state that, according to Mr. Murchison, these subterraneous accumulations of rock salt and salt springs must be referred to marine deposits of high antiquity, chiefly *Permian*, and not, as has been sometimes supposed, to the desiccation of any inland sea of comparatively modern date.

† *Geol. Trans.* 2nd Ser. vol. vi. p. 112.

poraneous with these. The deposits in both districts are of marine origin, and those at the mouth of the Tagus extend over an area of more than a thousand square miles.

Numerous and extensive Tertiary formations are known to exist on the shores and in the islands of the Mediterranean, most of them belonging to the Newer period, but some probably Miocene. The island of Zante is one of these, and the Apennine limestone, which is the underlying Secondary rock, is there covered by beds of a porous sandy limestone, succeeded by blue clay and marl, all the beds having partaken of the accidents of the older deposits, and being much disturbed. In Cephalonia also nearly the same sequence is observable, and beds of gypsum succeed the marls, and probably belong to the same epoch.\*

In the Ionian Islands, at least in Corfu, which has been chiefly the object of investigation, compact beds of Tertiary limestone, apparently of the Middle period, repose unconformably on the secondary rocks, and are associated with a number of clayey beds. Like the similar beds in Zante, many disturbances have taken place since their deposition, and they are inclined at a high angle.†

\* Geol. Trans. 2nd Ser. vol. v. p. 404.

† I am indebted to Capt. Portlock, R. E., at present in the Ionian islands, for this information with regard to Corfu. It is not unlikely that many other islands in the Mediterranean will be found to possess the same general character.

## CHAPTER XXXVIII.

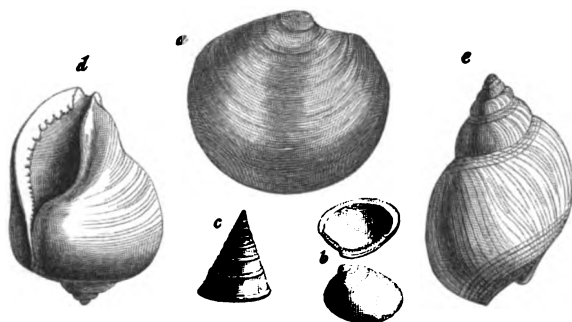
## THE NEWER TERTIARY OR "PLIOCENE" DEPOSITS IN EUROPE.

IF the reader has been struck by the extent and importance of the Older Tertiary deposits in Western Europe, or the development of the Miocene strata in the central and eastern part of the Continent, he will be no less interested in the contemplation of those mountain masses of yet newer date, which are to be traced in the South, and which occupy a prominent place on the coasts of Italy and Sicily, in the Morea, and in almost all the islands of the Eastern Archipelago.

Of this great series of Newer Tertiaries, the group of strata which has been longest known, and is most minutely described, is that which is exhibited along the whole length of Italy, on the flanks of the great Apennine chain, both towards the Mediterranean and the Adriatic. The strata attain in some parts a very considerable thickness, and are raised high above the level of the sea; they are throughout extremely fossiliferous, and there would appear to have been many successive deposits conducting gradually from the Miocene strata in the North, to the newest Sicilian beds in the South.

The general lithological character of the Sub-Apennine formations, is that of greyish brown or blue marls, containing calcareous matter, and usually overlaid by, but sometimes alternating with, thick sandy beds. Fossil

marine shells abound in all parts of the formation, and they are sometimes associated with beds of lignite, and a few fresh-water shells.



FOSSIL SHELLS FROM THE PLIOCENE DEPOSITS OF ITALY.

<i>a. Lucina menardi.</i>	}	Sicilian beds.
<i>b. Nucula poli.</i>		
<i>c. Trochus cingulatus. Brocchi.</i>	}	Sub-Apennines
<i>d. Buccinum lævigatum Lam.</i>		
<i>e. Buccinum mutabile. Lam.</i>		

The Sub-Apennine marls attain a very considerable thickness (said to amount to as much as two thousand feet in the hills near Parma), and pass occasionally into a compact limestone. They are sometimes seen reposing immediately on the Apennine limestone, but at other times a bed of gravel intervenes, and occasionally volcanic rocks are superimposed, or volcanic tuffs appear interstratified with the marls. The sandy beds are usually of a yellow colour, and pass into conglomerates, and at certain points, where it would appear that rivers have entered the sea during the formation of these beds, there exists clear proof of fluvial action, and the fragments of numerous fresh-water shells are sufficiently abundant.



It should be clearly understood that the word *Basin* does not at all apply to these Tertiary formations of Italy. They are, for the most part, strictly marine deposits, formed apparently in the neighbourhood of land, and upon a line of coast shelving into a deep sea. Similar formations, although on a smaller scale, are probably still going on both in the Mediterranean and the Adriatic, and these may one day be elevated and exhibit phenomena strictly analogous.

It would be reasonable to expect, from the diminution in intensity of subterranean disturbances in northern Italy (proofs of the gradual decay of volcanic action being there sufficiently evident), and from the increased extent and magnitude of such movements in the south, that we should find in the latter district the most recent strata that have been elevated into dry land; and there is no doubt of the fact that the Sicilian beds, and others in the neighbourhood of Mount Vesuvius, are newer than those of the Sub-Apennines. They occupy also a very considerable tract, and in the south of Sicily hills two thousand feet high are entirely composed of one of the uppermost members of the series. An instance of this is represented in the annexed diagram, where the bed marked 'Great Limestone' is of the newest Pliocene period.

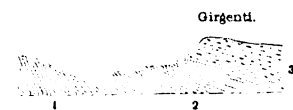


SECTION NEAR SYRACUSE.\*

- \* 4. Great limestone.
- 3. Schistose and arenaceous limestone.
- 2. Blue marl, with fossil shells.
- 1. Blue and white clay and marl—no fossils.

The newer Tertiaries in the vicinity of Naples consist chiefly of volcanic ashes, &c., erupted in ancient times from Vesuvius, and forming hills from five hundred to more than two thousand feet high, composed of an immense series of tufaceous strata, alternating with distinct lava currents. The island of Ischia is almost entirely made up of similar deposits, a lofty hill in its centre, which rises to the height of 2,600 feet above the level of the sea, being composed of an indurated tuff interstratified with argillaceous marl, and containing abundance of recent marine shells. In the hills immediately behind Naples the same phenomenon has been observed, and the submarine tuffs, lavas, and clays of Campania very much resemble those in Sicily round the base of Mount Etna.

The principal Tertiary deposits in Sicily consist of marls, expanded to a great thickness and only distinguished from one another by slight differences of colour and mineral character, succeeded by limestones, at first argillaceous, but afterwards white and compact. The lowermost of the marly beds are often greatly contorted, and contain sulphur, salt, and gypsum, in great abundance, but no organic remains, with the exception of the skeletons of fish in some of the gypseous beds.



SECTION NEAR GIRGENTI, SICILY.\*

A bed of blue marl [marked (2) in the above diagram] overlies the older and paler coloured strata just alluded to, and is well exhibited near Girgenti. It greatly resembles a

\* The references are the same as those to the last diagram.

similar deposit in the Sub-Apennine hills, and encloses also fossil shells and corals in a beautiful state of preservation, most of the species being identical with existing species obtained from the neighbouring seas.

To the blue marl succeeds a sandy limestone (3), often becoming a calcareous sand, and containing numerous fragments of shells, but occasionally assuming an oolitic or pisolitic character. In some parts of Sicily this bed is replaced by yellow sand, beds of which, several hundred feet thick, and with occasional layers of shells, repose upon the blue shelly marl.

Lastly, there appears (chiefly in the neighbourhood of Syracuse) a much more extensive limestone formation of the Pliocene period, called by Mr. Lyell 'the great limestone of the Val di Noto,' (4). (See diagram, p. 44.) This bed sometimes attains a thickness of seven or eight hundred feet, and although varying considerably in mineral character, it seems to possess throughout the appearance of a rock precipitated from the waters of mineral springs, being very thickly bedded and often without any lines of stratification. It is of a yellowish white, or pure white colour, abounds in natural caverns, and contains shells often entire but more frequently imperfect, and almost all of those that have been determined are identical with species still found living in the Mediterranean. This *great limestone* is most prevalent in the Val di Noto, the southern extremity of Sicily, but appears also in the centre of the island, capping a hill at the height of three thousand feet above the level of the sea.

The Sub-Apennine Tertiary beds of which I have already spoken, and which are chiefly developed on the western side of the Apennine chain, are also met with on the eastern side coming down to the Adriatic, and

are continued across the Straits of Otranto to the coast of Albania, occupying the islands on the coast of Greece and stretching into the Morea. Little is known accurately of the real age of these eastern parts of the deposit, but the labours of Mr. Strickland have been successfully devoted to a description of the Geology of the island of Zante, which has been alluded to in the last chapter, but which consists also partly of Pliocene strata.

Overlying the gypsum beds of Cephalonia and the blue clay and marls of Zante, there are found beds of porous yellow limestone, which belong unquestionably to this newer epoch. As we advance further southwards, we find the upper and newer beds to preponderate, and in the Morea they may be considered to occupy almost the whole country, varied only by the effects of recent volcanic action.

In northern Europe the valley of the Rhine between Coblenz and Cologne, is found to contain an interesting deposit of the Pliocene period, which has been described in some detail both by German Geologists, and also by Mr. Horner in the Transactions of the Geological Society of London.\* It may be called the Braunkohl, or Brown-Coal formation, and is remarkable as containing the most important and massive deposits of vegetable matter that have hitherto been found in Europe in any strata of newer date than the Carboniferous period.

The base of the brown-coal formation seems to consist generally of loose siliceous sand, sometimes passing into a sandstone and sometimes into a conglomerate, and which

\* Second Series, vol. iv. p. 447. See also Von Dechen, Karsten's *Archiv*, vol. iii. for 1831. Von Moll's *Jahrbuch*, vol. iii. for 1815, and Leonhard's *Zeitschrift für Mineralogie*, 1828, &c.

usually contains a thin leafy bituminous lignite called Paper-coal, and fragments of silicified wood, often changed into chalcedony, and occasionally into semi-opal.\*

The laminae of paper-coal are associated with thin earthy and friable siliceous plates, not unlike the *polirschiefer*, or polishing slate of other parts of Germany.

Beds of clay of various kinds, containing some kinds valuable for the potter and others used in pipe-making, often succeed these siliceous beds, and form the actual base of the lignites. In many places the clay is itself mixed with earthy lignite, and in many others it is extremely pyritous.† The lignite which is accumulated upon these clays is of various kinds, a considerable part of it consisting of solid wood, showing little change in specimens taken out of the mine and dried, but bedded in a manner precisely similar to coal, and of a deep black colour. This lignite contains, however, a somewhat large percentage of earthy matter, and although burning with a bright flame, is incapable of standing a blast, and has been hitherto little used for economical purposes. As might, perhaps, have been expected, the different beds of vegetable matter exhibit great differences in this respect, and the fibrous texture of the wood is often so little changed as to admit of portions being actually used as timber in the mines, while, in other cases, the interior is converted into

\* A large and beautiful specimen of this latter kind, in which the woody structure is perfectly preserved, was brought by Dr. E. D. Clarke from Transylvania, and is now in the Woodwardian Museum of Geology, in the University of Cambridge.

† At Friesdorf, on the left bank, and at several places on the right bank of the Rhine, this pyritous clay has been used extensively in the manufacture of alum. Crystals of gypsum are often found between the layers of alum slate, and clay ironstone is also common, a thickness of nine feet and a half having been found in thirteen layers, near Rott.

carbonate of iron, or the substance of the wood replaced by a coarse quartzose sand.

The lignite is also remarkable for the fossils associated with it, and these consist of the remains of insects, mollusca, fishes, Batrachian reptiles, and even quadrupeds. They are usually in bad condition, and occur chiefly in the paper coal. It is not uncommon to find the lignite resting immediately on masses of tabular basalt, (near Hachenburg, in the upper part of the valley of the Nister, this is more particularly the case,) and it frequently occupies considerable elevations, being found on the top of the higher districts of that table land which extends over the northern parts of the Duchy of Nassau towards the Vogelgebirge.

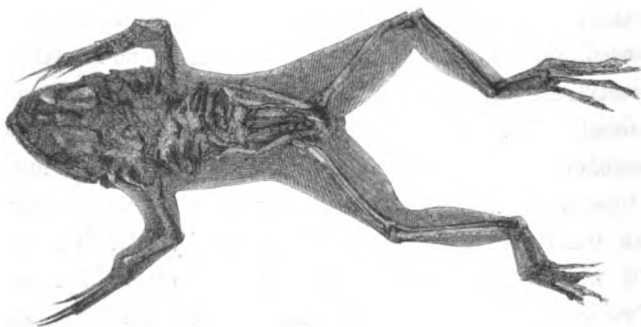
Belonging to a period posterior to that of the Molasse, and probably nearly the same as that during which the brown-coal was being deposited, we must next notice a remarkable lacustrine deposit of highly fossiliferous marls and limestone, occupying a hollow in the molasse near Ceningen, where the Rhine issues from the Lake of Constance. The lower beds in this spot consist of cream-coloured marlstones, containing the remains of plants (chiefly dicotyledonous), of fishes, and of the shells of fresh-water animals. These are overlaid by several bands of fetid marlstone and limestone, all of them exceedingly fossiliferous, and attaining a considerable thickness. In one of the limestones there has been found by Mr. Murchison the nearly perfect skeleton of a fox, little different in specific character from the recent fox; and the same quarries have also yielded fishes of large size, a turtle three feet in length and numerous crustaceans and insects perfectly preserved.

It is clear that this formation must be comparatively recent, but the horizontal beds of which it is composed present escarpments several hundred feet above the Rhine, without any barrier between them and the river.\*

The Pliocene strata occupy a very extensive region in Southern Russia, and are well exhibited in the cliffs on the sea of Azof, where beds of white and yellow limestone contain several species of *Cardium* and *Buccinum* and large *Mastræ*, all of marine origin. Overlying these, and often reposing on intermediate sands and siliceous grits, there also occurs a widely spread limestone, in which are many remains of mollusca that must have lived in brackish seas; and these beds are considered to be an extension of similar shelly deposits in the Crimea and the neighbourhood of Odessa, described by M. de Verneuil. (See Trans. Geol. Soc. of France, vol. iii. p. 1.)†

\* Geol. Trans., 2nd Ser. vol. iii. p. 277.

† See also Proc. of Geol. Soc., vol. iii. p. 729.



*RANA DILUVIANA, GOLDFUSS.*

*Paper Coal, near Bonn.*

## CHAPTER XXXIX.

THE FOSSIL PLANTS AND INVERTEBRATA OF THE TERTIARY  
EUROPEAN STRATA.

THE strata of the Tertiary period are, beyond comparison, richer than any others in those organic remains from which the Palæontologist derives his account of the flora and fauna of the past conditions of the earth. Each separate one of the numerous basins described in the preceding chapters, and each line of coast which exhibits a deposit newer than the chalk, exhibits also, on careful examination, a special group of fossils, often, no doubt, resembling those found in other localities, and sometimes containing species still represented, but, notwithstanding, each in itself local, and to a certain extent characteristic.

But these groups, possessed undoubtedly of great local interest, and often of much general interest as bearing on disputed points in Geology, are not of such a nature as to admit of detailed description in a work like the present. Many extensive beds contain little more than the remains of shells, differing only in specific character from species still abundant in various parts of the world; and these objects clearly do not require, nor do they allow of any such general sketch being given of their nature, as I have attempted to give of the extinct species of other formations.



But although this is the case, and it does not seem possible to attempt any special notice of even the great divisions of the Tertiary period, I think it will be found that, with a little consideration, some leading idea may be acquired of the real peculiarities of each. In speaking, for instance, generally of the Tertiary fossils, and proceeding in the order hitherto followed, I shall have occasion to describe at some length among the plants that singular group of fossil fruits found in the London Clay. Passing on to the animals of lowest organisation, I shall dwell upon the "foraminifera," which form entire beds in the Paris Basin, and in many of the Tertiaries on the shores of the Mediterranean, and the infusorial animalcules, which are characteristic of the Tertiary period in some localities in Germany and elsewhere. I shall also mention the insects of the fresh-water Eocene bed of Aix in Provence, the crustaceans of the London Clay, and the more remarkable forms of the shells in the different strata of the whole group.

The description of the vertebrata of the Tertiary period will introduce the reader to some other well known groups of strata characterised by them. Of these the marine beds of Monte Bolca and the London Basin, and the fresh-water beds of Oeningen contain numerous fossil fish; the London Clay and the newer Pliocene beds of the Rhine, most of the few reptiles of the period; and the London Clay and Paris Basin, the still fewer remains of birds. The latter bed will again be an object of interest when speaking of the remains of Mammalia, so many of which have been found in the gypsum beds of Montmartre; and the Miocene beds in the valley of the middle Rhine will be alluded to in describing their remarkable fossil, the *Dinotherium*.

In this way most of the different strata of which the organic remains possess any peculiar interest will be successively brought under review, and of the rest I have already, in some cases, given figures of such of their shells and other fossils as are characteristic, and any further allusion would be necessarily tiresome from its minute detail. I proceed now, therefore, to consider the Tertiary fossil remains of plants.

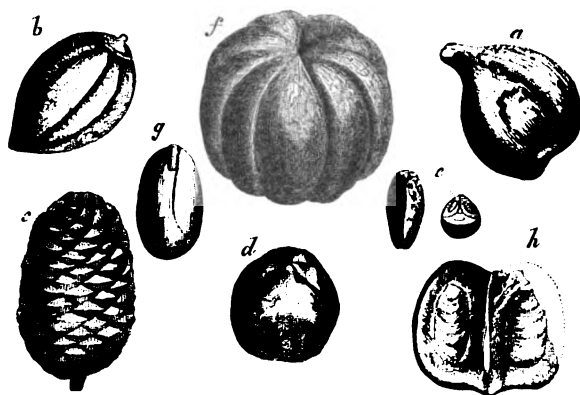
Besides the fruits of the London clay, fragments of wood have been not unfrequently found both in the London and Paris Basins, and elsewhere, among Tertiary deposits. These fragments of wood, and the leaves which sometimes accompany them, are generally Dicotyledonous and indicate differences by no means considerable from existing species; but it is worthy of remark that in the older strata the analogies are rather with the trees of tropical and southern latitudes, than with those now found in any part of Europe.

In the newer Tertiary deposits, as I have observed in speaking of the Brown Coal of the Rhine Valley, the vegetable matter is often very little altered, and the structure of the wood is completely preserved. Similar trees also are still growing in the neighbourhood, and in some localities entire beds are made up of the leaves of poplars and forest trees, alternating with extremely thin laminae of clay, and forming what is called the Paper Coal.

I have already mentioned that fragments of silicified and opalised wood are not unfrequent in some districts containing newer Tertiary deposits.

But all these remains are of very inferior interest compared with the singular fossil fruits which abound in the Isle of Sheppey, and from the examination of which

several hundred species of plants have been determined, all of them extinct, and all exhibiting analogies with the plants of warmer climates. These have been made the subject of very careful investigation, and a work (of which the first part only has hitherto appeared) has been undertaken by Mr. Bowerbank, describing the various species, and figuring those specimens most instructive and characteristic. I have availed myself of these descriptions in drawing up the following account of some of the genera, and am indebted to the kindness of Mr. Bowerbank for granting permission to copy a few of his figures illustrating the subject. The species I have selected for figuring are for the most part sufficiently common, and are those whose analogies with existing fruits are most clearly made out.



GROUP OF FOSSILS FROM THE LONDON CLAY.

- |   |   |
|---|---|
| <i>a.</i> <i>Nipadites elegans</i>            | <i>e.</i> <i>Tricarpellites communis</i>  |
| <i>b.</i> <i>Hightea fusiformis</i> .         | <i>f.</i> <i>Cucurbita variabilis</i>     |
| <i>c.</i> <i>Pterophyllodes richardsoni</i> . | <i>g.</i> <i>Faboides ovata</i> .         |
| <i>d.</i> <i>Copaucoides inflatus</i> .       | <i>h.</i> <i>Wetherellia variabilis</i> . |

Among the most abundant of the innumerable fossil fruits of Sheppey, there is a group (called by the local

collectors of such fossils, *Fossil Figs*), which have been considered by M. Brongniart to be very nearly allied to the fruits of the *Pandanus*, or Screw Pine, a singular tribe of plants inhabiting warm climates, and having the aspect of gigantic pine-apples, with arborescent stems.\* This and an allied genus, (*Nipa*,) (to which, according to the researches of Mr. Bowerbank, the fossil is still more nearly allied,) are met with in the islands of the Indian Archipelago, and are found to flourish most in "watery and marshy places, where the soil is black clay, and which are frequently covered with water. Hence it (the *Nipa*) is observed at the mouths of great and rapid rivers, and also in such places as are overflowed by the sea, or by brackish water (as it grows best in soil impregnated with salt). Its height, however, is trifling, and it does not merit the name of a tree."† Mr. Bowerbank states that the resemblance between the Sheppey fossils and the fruits of *Nipa* is so close as to leave scarcely a doubt of their being members of the same genus. He, therefore, rejects the name *Pandanocarpum*, proposed by Brongniart, and has called the genus *Nipadites*. Thirteen species have been already determined, of which the one figured (*a*, p. 54) is the most abundant, and spe-

\* The Pandaneæ differ very considerably in their general appearance. Some species resemble the palm tribe, and of another the following notice appears in Mr. Backhouse's work on the Australian Colonies already quoted. "One of the remarkable vegetable productions of this island (Norfolk Island) is called the Norfolk Island Grass-tree. Its stem is marked by rings where the old leaves have fallen off, and is an inch and a half in diameter; it lies on the ground, or climbs like ivy, or winds round the trunks of trees. The branches are crowned with crests of broad sedge-like leaves. From the centre of these arise clusters of three or four oblong red pulpy fruit, four inches in length, and as much in circumference. When in flower the central leaves are scarlet, giving a splendid appearance to the plant, which sometimes is seen twining round the trunk of the princely tree-fern."—*Backhouse*, &c., p. 256. See also Notes, pp. 254 and 257.

† Bowerbank, *loc. cit.*, p. 8.

cimens of it vary in length from half-an-inch to four inches and a half, the breadth and thickness varying also exceedingly. In another species (*N. giganteus*) the fruit attained the length of seven inches, and the seed is also much larger in proportion than that of the former.

The small cones of a tree (fig. c, p. 54), said by Mr. Bowerbank to belong to the *Proteaceæ*, are also common among the fossils of the Isle of Sheppey and Herne Bay. They are, like the former, nearly allied to an existing genus (*Pterophila*), which in this case is an inhabitant of New Holland; and a striking similarity was observed in the structure of some of these fossils when compared with the wood of small stalks of similar cones from Sydney.

A genus named *Cupanoides* has been determined from some Sheppey fruits in a very good state of preservation, and seems to bear, in many respects, a great resemblance to the *Anomum*, and other plants belonging to the family of the *Canneæ*. It is sufficiently common, and appears to have been the produce of trees or shrubs probably of no great size; the seed is usually kidney-shaped, or rather of the form of the common edible mussel (fig. d, p. 54).

*Wetherellia* is a genus established to include certain pulpy fruits divided into two lobes by the expansion of the seeds when ripe, and is well known throughout the Isle of Sheppey by the name of *Coffee*, to which some of the sections of the fruit bear a strong resemblance (fig. h, p. 54).

It appears, however, that when in a recent state, the cells of this berry were filled with juice like those of the orange, and it is probably for this reason that, in spite of the great number of the specimens examined, not one has been found in a sufficiently perfect state of preservation

to show (except by the position of the seeds) which end is the base and which the apex.

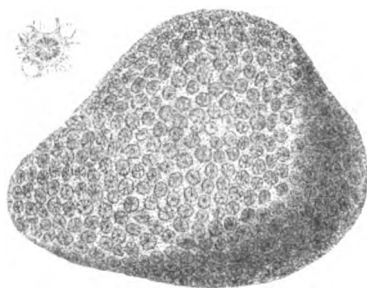
Another very common fruit ought not to be omitted, namely, the *Cucumites* of Mr. Bowerbank (fig. *f*, p. 54), which, both in outward form and internal structure, so closely resembles various members of the recent genus *Cucumis*, that no reasonable doubt can remain of the fossil being referrible to the Gourd family. Most of the specimens are much compressed laterally, owing to the extremely succulent nature of these fruits, and they even seem to have been exposed to long maceration previously to the process of fossilisation being commenced. The whole of the interior of the fruit was filled with small seeds, embedded in the cellular internal mass without any apparent order or arrangement.

The last of the London Clay fruits I shall notice are certain bean-shaped seeds. Some of these are contained in pods, and appear to be either identical with or closely allied to the *Acacia*, and belonging to the natural group of the Mimoseæ. Other bean-like seeds are also found, and have been referred to a genus "*Leguminosites*:" they were probably leguminous fruits, resembling those of the common Laburnum. The *Faboidea* (fig. *g*, p. 54) is more anomalous, and although resembling the common scarlet-bean in external appearance, exhibits peculiarities in the nature of the attachment of the seed to the placenta which distinguish it from any recent plant. Not less than twenty-five species of this genus have been determined, all of them from Sheppey specimens.

I shall not here offer any extended remarks on the general deductions that may be drawn from the fact of the existence of these fruits at the period of deposition of the London Clay, but it can hardly have escaped notice that

all the analogies they offer to existing plants are with generic forms which are rarely, if at all, represented in the temperate zone of the Northern Hemisphere. They belong either to tropical, or at least to southern types; and that this is no accidental resemblance will appear from every fact hitherto determined as to the nature of the animals, as well as vegetables, of the period. It is a point of no little interest, but it is one which still requires much careful investigation and unprejudiced discussion.

Quitting now the consideration of these vegetable fossils, and proceeding to the lower forms of animal life, we find that the corals of the Tertiary formations are, for the most part, of small size, and resembling those of the recent period. This is well shown in the beautiful specimen which I have figured, and which can hardly be distinguished from a recent species. It was found in the sandy beds of Bracklesham Bay by Mr. Bowerbank, and several specimens have since been obtained from the same and other localities.



ASTREA WEBSTERI. Bow.

*London Clay.*

But although the corals offer so little that need detain us, the remains of Zoophyta of other kinds are very abundant, although not indeed characteristic of Tertiary strata.

Among these are the infusorial animalcules (whose minute siliceous skeletons sometimes make up whole beds of earthy but organic matter), and the *Foraminifera*, probably scarcely removed from Polyps in point of complexity of organisation, but whose remains are so numerous in some of the Mediterranean and other Tertiary limestones, that the imagination is lost in the attempt to contemplate so vast an exuberance of animal life. And yet we are in a condition to prove that formations of the same kind are still in progress, and that the solid matter which these animals secrete, and the skeletons which they leave behind them after death, still form extensive deposits at the bottom of deep seas, producing effects for which, at first sight, they appear utterly inadequate.

In the first place, with regard to the Infusorial animalcules, their dimensions are so minute that it is scarcely possible to form an idea of the conditions of their existence. In the smallest of them there have been discovered from four to six stomachs, and a mouth surrounded with from ten to twenty *cilia* (or hair-like appendages), while others may be seen to possess a secreted shell, consisting of pure colourless and transparent silex, generally sculptured with a beautiful, well-defined and more or less complicated pattern, which makes it easy to distinguish one species from another. Of the most minute of these simple but perfectly organised animals, it would require more than ten millions of millions of individuals to fill the space of a cubic inch; and yet in some places beds of siliceous powder are absolutely and entirely made up of remains secreted by species little larger than these, and possessed of similar organisation.\*

\* A mass, more than twenty feet thick, of light siliceous earth was discovered not many years ago in the Hanoverian province of Lüneburg, and was found to



A powder of this kind has long been known, and is used in the arts under the name Tripoli (but called by Werner 'Polir schiefer,' from its use in polishing metals). It is obtained from Bilin in Bohemia, and a similar stone is also found at Planitz, near Zwickau in Saxony, and in other places. It consists almost wholly of infusoria cases, perfectly preserved, and supposed by M. Ehrenberg to have been exposed to a very considerable heat, completely evaporating the carbon derived from the plants on which the animals lived, as well as the organic carbon of the animals themselves. A single druggist's shop in Berlin consumes yearly more than 20 cwt. of the polishing slate, and yet there seems a sufficient supply for purposes of practical utility, although a cubic inch, weighing 220 grains, contains upwards of forty thousand millions of individuals lying together, closely compressed and without cavities, and also without any foreign cement. The annexed figure represents the species of which almost the whole mass is made up.



GAILLIONELLA DISTANS.  
Magnified 300 times

consist almost entirely of beautiful and perfectly preserved coverings of infusorial animalcules, very various, but belonging to known species found living in the ponds in the neighbourhood. These siliceous skeletons are individually quite invisible to the naked eye, although accumulated to so considerable an extent. See Ed. Phil. Jour. for 1838, p. 377.

Prof. Rogers has described (States Report, 1840,) a bed of infusorial clay, consisting of an impalpable siliceous powder, derived from the cases of microscopic animalcules, and varying in thickness from twelve to twenty-five feet. Not less than 214 species of these animals have been determined from different parts of America, and some of them have been observed in turfy and argillaceous ground as much as sixty feet below the surface, but still in a living state. Ed. Phil. Jour. for 1842, p. 153.

Fragments apparently organic, and resembling the cases of infusoria, have even been detected in some of the rocks of oldest date altered by igneous contact. May we not hope that a more careful examination may discover them also in the fossiliferous slates, at least in those cases where the siliceous has not been collected into veiny masses by the action of crystalline forces.

The family of the *Bacillaria* is that to which the Tertiary species found at Bilin, and indeed most of the others very abundant, have been referred. This family contains also the most abundant recent forms.\*

The great abundance of these minute animals, so great indeed that their remains actually form large mineral masses, and the fact that, whenever animal and vegetable matter is undergoing decomposition in water, they are always present in multitudes which it would confound the imagination to attempt to reckon, makes it a point of no little interest that we should learn, if possible, the nature of the task imposed upon them; assuming, as we may safely do, that there can be no natural family of vegetables or animals developed to any considerable extent without the individuals or the collective body occupying a really important place in the great plan of Creation. I cannot hope to offer any remarks of my own on this subject so happily applicable as the conclusions arrived at by Professor Owen, and thus expressed in his Lectures on the Invertebrata:—

“Consider,” he observes, “their incredible numbers, their universal distribution, their insatiable voracity, and that it is the particles of decaying vegetable and animal bodies which they are appointed to devour and assimilate.

“Surely we must, in some degree, be indebted to these ever active invisible scavengers for the salubrity of our atmosphere. Nor is this all: they perform a still more important office, in preventing the gradual diminution of the present amount of organised matter upon the earth. For when this matter is dissolved or suspended in water, in that state of comminution and decay which immediately precedes its final decomposition into the elementary gases,

\* Taylor's Scient. Mem., vol. i. p. 405.

and its consequent return from the organic to the inorganic world, these wakeful members of nature's invisible police are everywhere ready to arrest the fugitive organised particles, and turn them back into the ascending stream of animal life. Having converted the dead and decomposing particles into their own living tissues, they themselves become the food of larger Infusoria, and of numerous other small animals, which in their turn are devoured by larger animals, and thus a pabulum, fit for the nourishment of the highest organised beings, is brought back by a short route from the extremity of the realms of organised matter. These invisible animalcules may be compared in the great organic world to the minute capillaries in the microcosm of the animal body, receiving organic matter in its state of minutest subdivision and when in full career to escape from the organic system, and turning it back by a new route towards the central and highest point of that system."\*

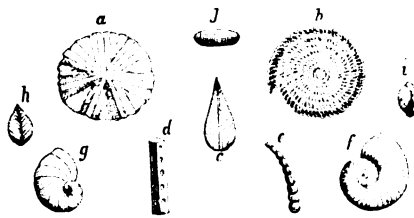
The *Foraminifera*, of which a very large number of species abound in the Mediterranean seas, were described by M. A. d'Orbigny in an early volume of the *Annales des Sciences* as small cephalopodous animals.† The shells of these singular and minute animals undoubtedly bear a very strong resemblance to the multilocular habitations of extinct cephalopods, and it would have been, to a certain extent, consistent with analogy that this resemblance should have extended to the animal. M. Dujardin,‡ however, has since stated, that the shell is not in any case internal, (as had been supposed by M. d'Orbigny) and that the animal is absolutely without any organs of loco-

\* Owen's *Lectures on the Invertebrata*, p. 27.

† This opinion has, however, been greatly modified in the more recent essays of M. D'Orbigny on this subject, and he has lately described a considerable number of recent species from the seas on the coast of South America.

‡ *Annales des Sciences*, 2nd Ser. vol. iii. p. 108.

motion, or even of respiration, being of exceedingly low organisation, and composed of a number of polyps which occupy the different chambers, the general form of the animal differing in each species. These views of M. Dujardin appear to have been verified by later observations, and there is little doubt that the animal belongs to a class lower in the scale of organisation than any of the mollusca. It is to be lamented that we have as yet no descriptions that can be depended on of the minute anatomy of these singular beings.



GROUP OF FORAMINIFERA.

- |                  |                  |
|------------------|------------------|
| a. Lineolaria.   | f. Operculina.   |
| b. Nummulites.   | g. Polymorphina. |
| c. Frondiculina. | h. Frondiculina. |
| d. Vinculana.    | i. Triloculina.  |
| e. Marginulina.  | j. Alveolina.    |

(Natural size.)

The shells of Foraminifera vary in size from dimensions perfectly microscopic to the diameter and proportions of a crown piece, and some, the larger species, being shaped like a coin, have received the generic appellation of *Nummulite*. Nummulites abound in the later Secondary, as well as the Tertiary rocks, and actually form almost the whole mass of many extensive strata, while the individuals of a species of far smaller size, the *Miliola* (so called from its resemblance to a grain of millet seed), entirely compose several thick beds of the calcaire grossier, in the neighbourhood of

Paris.\* Other species, about the size and shape of a small pea, compose the great Cretaceous limestone formation at the head of the Adriatic, and a range of hills about 300 feet in height, in North America, is said to be also entirely made up of similar fossils. Dr. Buckland has well observed that "the remains of such minute animals have added much more to the mass of materials which compose the exterior crust of the globe than the bones of Elephants, Hippopotami, and Whales."†

The most remarkable peculiarities of structure in these fossils will be seen by reference to the annexed engraving, in which some of the characteristic species of tolerable magnitude are represented. Their shape varies indefinitely; and this is not extraordinary, if the shell is to be looked on merely as the calcareous covering of a number of independent polyps. The Nummulite is perhaps the genus most widely distributed, and that which attains the largest size. Its shell is divided into a vast multitude of very small chambers, regularly arranged, and differing but little from one another in magnitude. The chambers communicate by means of a small aperture in the wall of separation between each two of them, and it is probable that each chamber was the habitation of an individual polyp. This kind of compound life is not confined to the animal now

\* The abundance of foraminifera in certain parts of the calcaire grossier is such that a cubic inch of stone from the quarries of Gentilly was calculated to contain, on an average, 58,000, and the beds are of great thickness and considerable extent. It may even be asserted, without fear of contradiction, that the capital of France, as well as the towns and villages of the neighbouring departments, are almost entirely built of Foraminifera; and these little fossils are scarcely less abundant in other Tertiary formations, extending in the South of France from Champagne to the sea, and being found also in the basins of the Gironde, and again in that of Vienna. The cretaceous beds also abound in them, and they have been discovered even in the lowest beds of the Oolites. See Edin. New. Phil. Jour. 1842, p. 3.

† Bridgewater Treatise, vol. i. p. 386.

under consideration, but is common to several genera forming distinct families. The individual members of each compound group possess usually a community of nutrition, but it is very doubtful whether there is also a community of sensation. In other words, the food taken and digested by the individual polyps is appropriated to the support of the general body; but they act independently of one another, and when one is touched or injured, neither the central mass, nor the polyps at a distance, exhibit any mark of sensation.\* It is worthy of remark, that the very great abundance and wide distribution of these animals in existing seas, and of their remains in rocks of the Cretaceous and Tertiary periods, would of itself suggest the probability that they are not of very complicated organisation. Generally speaking, the minute animals floating constantly about in myriads in the water, and those which, although attached, are multiplied so rapidly as to leave sub-marine mountains as the monuments of their former existence, belong to the lower tribes of the Zoophyta; and it would be a new and anomalous fact if the most highly organised of the Invertebrata, the Cephalopoda, thus rivalled the most simply organised beings in this matter, and also in their horizontal and vertical range during the more recent Geological periods. Even the Pteropoda are now looked upon by some naturalists as very much lower in the scale than they have long been considered, and if they are taken away, there remains no important tribe of animals which have a complicated organisation forming an exception to this apparently general law.†

\* General Outline of the Animal Kingdom, by Prof. R. Jones, p. 28.

† The most abundantly developed animals in existing seas consist of some genera of Pteropoda (*e. g. Clio.*), of the coral polyps, the infusorial animalcules, the *Acalephæ*, and some of the lower forms of molluscous articulated animals and cirrhopoda. The extent to which these abound may be in some measure conceived

The remains of Echinodermata are not by any means abundant in Tertiary deposits generally, but they are occasionally met with, and are not rare in particular localities. Both the London Clay and the Crag contain several species; and from the former I have figured an *Asteria* nearly allied to existing forms. In this specimen one of the five rays is



ASTERIA (undescribed species).

(*London Clay.*)

shorter than the rest, a peculiarity most probably owing to an accident received during the life of the animal. Several species of *Echinus*, and of genera nearly resembling *Echinus*, an *Ophiura*, a *Pentacrinus*, and a few others, complete the scanty list of these animals found in the Tertiary strata. The Echiniform species are chiefly confined to the Continental beds, and are, perhaps, most abundant in the Miocene beds of Malta, where they attain a very large size.

from the following fact with regard to the *Medusa*, a genus of *Acalephas* often growing to a very large size, and forming the food of the largest Cetaceans.

“The number of small *Medusarizæ* in some parts of the Greenland seas is so great, that in a cubic inch taken at random there are not less than sixty-four, and in a square mile, supposing their thickness to be not more than a foot, (and there can be no doubt of its being far more,) there would be upwards of twenty thousand millions of individuals. Vessels are sometimes sailing for days together through masses of these animals.”

The *Beroë pilcus* and *Clio borealis* are almost equally abundant.

The Crustaceans of the Isle of Sheppey are very numerous : they belong, however, for the most part, to species of Lobster, Crab, and Cray-fish, which have not yet been described with sufficient care to admit of any general abstract being given of their peculiarities of structure. They are often exceedingly perfect, and must include a considerable number of extinct species.

Among the insects found in Tertiary formations, those from the Eocene strata of Aix, in Provence, are, perhaps, the most interesting, although those from the more recent deposits of Auvergne are also worthy of notice. In each of these cases the species that have been determined exhibit considerable approach to existing genera, and include several not easily distinguished from the insects still living in the vicinity.

The subject of the Tertiary Mollusca is one of peculiar interest to the Geologist, but one also which hardly admits of being presented to the reader in any other than a technical form. The species are exceedingly numerous, amounting to many hundreds even in particular localities, and only a small proportion of those that are common in one district are repeated in another. But the specific differences are small, and often almost inappreciable, while the general results deduced from their examination have reference rather to points of Geology connected with the age of strata, than to any zoological deductions of special interest.

There are, however, some important facts of this latter kind, and, amongst them, perhaps one of the most remarkable is the extreme rarity of the shells of Cephalopoda in all strata newer than the chalk, and the introduction of large carnivorous Gasteropoda, probably replacing them and performing their office,—one of no little consequence in the economy of nature,—of marine scavengers, devouring a



vast quantity of dead animal matter constantly floating in the sea. The introduction of the carnivorous genus *Cerithium* in the Eocene period was possibly required by the extinction of the Cephalopoda, and as the different species of *Cerithium* are known to abound chiefly in brackish water, while the cephalopodous molluscs are more strictly marine, the substitution may also have been needed by a change in the conditions of animal life. At any rate, it is undeniable that carnivorous Molluscs of lower organisation (Gasteropoda) succeeded to the Cephalopoda in the newer rocks, and became infinitely more abundant and varied in form than they had been in the older strata.

So large is the number, and so varied the grouping of the Mollusca in each fossiliferous bed of the Tertiary period, that the organic remains of these animals have been assumed by Mr. Lyell as the groundwork of his *per-centage* system of classifying the strata of the period. I have already alluded to this subject, and have ventured to offer an opinion as to the value of the method of identification in question.\* In these remarks, and in the few that will be here subjoined, I have been chiefly desirous of impressing on the reader the necessity of extreme caution in forming or admitting conclusions from such data, and the importance of possessing a large number of species, both of fossils and of recent analogues, before a conclusion is arrived at at all.

There can, I suppose, be no doubt, that where a large and tolerably perfect collection of recent marine shells is obtained from a given locality, affected by known circumstances of climate, depth, and temperature, this collection, considered as a distinct group, may form the proper element of comparison with fossils obtained from

\* See *ante*, p. 3, *note*, and pp. 6, 7.

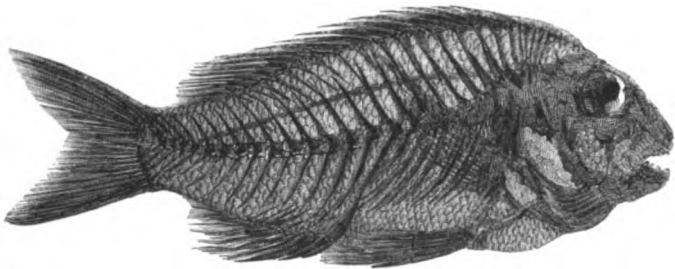
some other locality, provided that there also the circumstances of deposit are known to have been analogous; and in this way the determination of the age of the formation whence the fossils were obtained, may be determined relatively, by discovering what proportion the number of recent species among the fossils bears to the whole number of the species of fossils. In this way an isolated bed of unknown date may be satisfactorily proved to be of contemporaneous origin with another bed, whose position in the sequence is known by the distinct evidence of sections, when the two beds have the same proportion of existing species among the fossils found in them. When, however, a comparison is instituted between a miscellaneous collection of shells from all parts of the world, formed in perfect ignorance of the depth, climate, or temperature, at which the animal inhabitant lived, and a group of fossils brought together with similar disregard to the circumstances of deposition, then it seems most unreasonable to assume that any conclusion arrived at is valid, or that, on the strength of such evidence, the contemporaneity of doubtful with known beds can be determined.

But having said so much, I feel it right to add, that the general results arrived at by Mr. Lyell in his calculations have been, in most cases, either obtained by a due consideration of all circumstances, or have been strengthened by collateral evidence; and I only appeal against those who would apply his method hastily, and without considering the importance of those sources of error which he has himself ably and anxiously guarded against, and which he has not failed to put before his readers when first proposing his method for adoption.\*

\* Principles of Geology, 1st Ed. vol. iii. chap. v. p. 45.

## CHAPTER XL.

## EUROPEAN TERTIARY FOSSILS—VERTEBRATA.



SPARNODUS MICRACANTHUS. Ag.

It might naturally have been expected that in formations so nearly approaching our own time, and in the numerous and extensive fossiliferous beds, both of marine and fresh-water origin, that together make up the Tertiary group in Europe and elsewhere, the remains of *Fishes* should be extremely abundant; and should even exhibit satisfactory links, uniting the strange and anomalous animals of this kind found in the older rocks with those which inhabit existing seas. So far as regards the number of species and the variety of forms of fishes, such anticipations are fully realised by the facts of the case; but that no actual passage exists, connecting the earlier with the modern types of these animals, is now evident by the investigations that have been made

by M. Agassiz and other naturalists. An almost entirely new creation of fish, referred to new families, and forming two new orders, seems to have taken place before the commencement of the Cretaceous deposits, and to have been there associated with the older forms. At the close of the Secondary period all these older forms, with the exception of the species referred to seven families of Ganoids and Placoids, appear to have been completely destroyed, the newer forms becoming much more abundant and widely distributed, and not one species remaining identical with any that exist in Secondary rocks. Several distinct groups of fishes, containing in all as many as three hundred and fifty species, are thus added to the fauna of the Tertiary period by the Ichthyologist, and some of them exhibit anomalies quite as extreme as any that have been recorded from other formations. Of these groups the fishes of the London Clay, those of Monte Bolca in North Italy, and those obtained from the fresh-water deposit of Öeningen, on the Lake of Constance, are by far the most important, both in number and in the variety of species contained in them.

The fish-beds of Monte Bolca have supplied M. Agassiz with no less than one hundred and thirty-three new species, amongst which are many exhibiting the most singular anomalies of form and structure.\* Some of these belong to the family of *Chatodonts*, numerous species of which

\* The 133 species of Monte Bolca fish are thus distributed :

Ganoids	.	.	.	.	7 genera, 9 species.
Placoids	.	.	.	4 "	5 "
Ctenoids	.	.	.	36 "	69 "
Cycloids	.	.	.	30 "	50 "

They are associated by M. Agassiz with the fish from the calcareous schists of Mount Libanus, a locality extremely rich in fossils of this kind.

abound at the present day in the seas of the Torrid Zone, darting about in the shallow waters with the most restless activity, and remarkable for their singular forms and brilliant colours. Several genera of this family, represented by extinct species in the limestone of Monte Bolca, exhibit the oddest possible departures from the ordinary form of the class to which they belong, and some



SEMIOPHORUS VELICANS. *Ag.*

of them are peculiar to Monte Bolca. One genus (*Semio-phorus*) is characterised by its single dorsal fin, which rises like a large sail upon the anterior part of the body,

but is extremely low towards the tail. This fin rises immediately from the head, and to a height greater than the whole length of the body. The corresponding ventral fins are also exceedingly long and slender. The head is very large, and the vertical column massive, but the operculum (the covering of the gills) exceedingly minute. Some of the other genera of Chætodonts possess shapes not at all less extraordinary than this; the *Zanclus* having the third or fourth ray of its dorsal fin excessively elongated, and the *Platax* having a body about as high as it is long, and provided with very large dorsal and ventral fins having rays of the same length and extending along the body as far as the tail, thus making the height of the body, including these fins, three times as great as its length.

The Chætodonts are not, however, the only fish remarkable for the oddness of their shape which are found in the Monte Bolca beds. The *Gasteronemus*, a Cycloid genus, so called from a filament proceeding from its ventral fin, (*γαστήρ*, the belly, *νήμα*, a thread) has an exceedingly strange appearance, owing to the singular conformation of this fin, the large size of the pelvic bones which support it, and the great prominence of the abdomen. The small dimensions of the cranium also, and its large and high crests, render the species altogether as peculiar and anomalous as can well be imagined.

The *Carangopsis* is another genus, less different in its appearance from existing species. It is confined to formations of the Tertiary period, and has only hitherto been found at Monte Bolca. It belongs to a great family, of which the Mackerel is a modern representative.

Lastly, the *Sparnodus*, a species of which (*S. micracanthus*) is figured in p. 70, is the only extinct genus hitherto

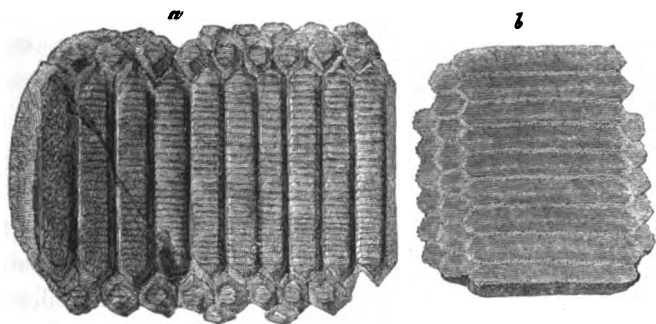
determined of an important natural family nearly allied to the Perch, and of the Ctenoid order. These fish have no palatal teeth, nor do they present the protracted jaws, or the cavernous swellings of the bones of the cranium of the genera which are most nearly allied to them in other points of structure. The body is generally of an oval shape and moderate size.

The Fossil fish of the London Clay are neither so numerous, nor so quaint in their external form, as are those I have just described from Monte Bolca. The number of species hitherto determined amounts, however, to seventy, which are most of them peculiar to the formation, and of eleven of the number the remains are not sufficiently perfect to admit of being referred to their natural families. Quite unlike the Monte Bolca fish, nearly half of the whole number of species belong to the Placoid order of M. Agassiz, and most of them to the Rays, the Sharks, and other nearly allied families. The teeth of Squaloid animals (those of the Shark tribe) are also found in the newer Tertiaries in considerable abundance, and in the island of Malta and elsewhere are often of a very large size.

The teeth of fossil species of the Placoid order of fish are so abundant, and so widely distributed, as to be objects of considerable interest to the Geologist, and the more so because the different genera offer varieties so marked that when once known there is no difficulty in determining the specific character, notwithstanding the many forms presented by the teeth of any one species, when taken from different parts of the mouth. They all, however, possess certain general characters, preserved even in the most extreme departures from the usual form, and consisting in the possession of a base or bony root, usually large and flat, but never conical, enclosed within the thickness of the

skin, and covered, where it projects into the mouth, by a coat of enamel, more or less thick, forming the crown of the tooth. They are not embedded in any alveolus or pit, nor are they attached to the jaws, but are endowed with considerable mobility, and cover the inside of the mouth and the palate.

Of all the Placoid fish of the Squaloid family, those of the genus *Carcharias*, have the greatest interest for the Geologist. In this genus the teeth are compressed, and of a triangular shape, and the enamelled edges are denticulated, especially in the upper jaw, where the largest and most powerful are placed. They usually incline backwards, the posterior part being more sloped than the anterior, and in this way it can be determined whether an isolated tooth belonged to the upper or lower jaw.



b, c. PALATAL TEETH OF MYLIOBATES.

The teeth of fish of the Ray tribe, more common in the London Clay than those of Sharks, differ from the latter, though not so much so in reality as might be supposed from comparing specimens of the two without reference to their structure and mode of growth. The genus *My-*



*liobates*,\* represented by many Tertiary species, is that which is most frequently met with in a fossil state. The teeth of most of the Rays of this tribe are of large size, flat-crowned, and placed adjoining one another, or are united at their edges by fine sutures, so as to form large plates like the squares of a pavement.

I have also figured the dental apparatus of a fish of the Ganoid order, belonging to a genus called by M. Agassiz, *Phyllodus*, because of the foliated structure of the flat pavement-like teeth with which the roof of the mouth was covered. These teeth differ considerably in their structure from those above described, of the Placoid order.



PHYLLODUS POLYODUS. Ag.

The family of the Pycnodonts, which includes several genera, in all of which this remarkable peculiarity exists, is entirely composed of extinct species, and has offered the greatest difficulties in the way of any satisfactory

\* A genus of gigantic fish, chiefly seen in warm latitudes, to which the *torpedo* rays are nearly allied, and which are connected with the sharks by the singular tribe of *saw-fish*, of which a species has also been determined from the fossils of the London Clay. They inhabit the depths of the ocean, and attain a very large size,—one specimen, stated to have been caught in the West Indian seas, having its body ten feet long, and thirteen feet in its greatest breadth, and the tail measuring fifteen feet. The use of this long naked tail, armed as it is with a sharp barb at the end, is probably to twine round the prey, and confine its struggles.

classification. In all the species, however, the root of the tooth is hollow and adheres to the jaw, differing in this respect from the flat and palatal teeth of the Placoid fish. The teeth appear to have been, almost without exception, better adapted for crushing than tearing, and were, probably, chiefly employed in grinding the shells of molluscs and crustaceans, an office in which they have been succeeded by a number of species of very different form and structure.

The fish found fossil at Oeningen are of fresh-water genera, and chiefly allied to the modern Carp and Tench ; but they also include an extinct species of Pike. The specimens are abundant, but the number of species hitherto described does not amount to twenty.

Reptilian remains are by no means so plentiful in the Tertiary strata as in those of older date, nor do they possess the same interest, either in themselves, or with reference to other types of structure. Three entire orders ceased to exist between the close of the Secondary and the commencement of the Tertiary period, and although a few new genera succeeded them, they by no means took the place of those who were destroyed, nor have they since recovered the important position once held by the species of this class among the Vertebrated animals. The Crocodilian, Chelonian, and Batrachian types are those which were retained, and which still exist, and to these was added the Ophidian tribe (the serpents), and a number of additional Lacertians, or lizards, of small comparative size. The remains of a serpent in the London Clay, in the Isle of Sheppey, offer the earliest indication at present known of any animal of this family ; but such remains were likely to be rare, and but little can be concluded from their non-appearance in older beds.

The Crocodilians, found also in the London Clay, have their analogies rather with the species living in the island of Borneo, than with the better known and more common Crocodile of the Nile. They do not, however, offer any important points of difference when compared with recent species, nor is there anything remarkable in their proportions or habits. The remains of Turtles, both fresh-water and marine, are far more common, and exhibit much greater variety. Many of these occur in the London Clay of Sheppey; others have been found in the same formation at Harwich; while others again are chiefly met with in the Tertiary limestones of the same date in the Paris Basin, or those of newer origin at Oeningen, and other localities. The greatest amount of deviation, however, from the existing form of these animals, observable in the fossil species, seems to be a combination of the jaws and buckler of a fresh-water genus, with the bony helmet of the marine Turtles.\*

The Serpent of the London Clay (*Palæophis*. Owen) appears to have been of large size, and of the proportions of the Boa Constrictor, which it resembled in some interesting points of anatomical detail.† The dimensions of some of the vertebræ indicate an animal more than eleven feet in length, which, probably, preyed on living birds and quadrupeds; and it is certain that no serpents of such dimensions and habits exist in the present day, except in warm and tropical regions. Other fragments would seem to warrant the conclusion that serpents of a much larger size were also in existence at the same period.‡

\* Owen's Report on British Fossil Reptiles. Report of Brit. Assoc., 1841, p. 192.

† Trans. Geol. Soc. 2nd Ser. vol. vi. p. 210.

‡ The remains of a species of frog, supposed to be extinct (the *Rana diluviana* of Goldfuss), have been found in the Paper-Coal near Bonn, a bed of the

The beds of the Paris Basin, among the many fossils they contain of deep interest to the Palæontologist, yielded to the active researches of Cuvier several species of birds. Among these there are found representatives of the following existing genera: Buzzard, Owl, Quail, Woodcock, Curlew, and Pelican. The fragments are most of them in bad condition, and, in some cases, mere impressions on the stone; but it is not a little interesting that the very small number already discovered should thus afford evidence of the existence of so many of the great orders into which birds are divided. In animals of this high organisation, it is especially interesting to find that the analogies presented by Tertiary fossils to recent generic and specific forms are singularly perfect.

In the English Eocene formations, the presence of fossil birds is much more rare than in the Paris Basin, but the specimens are, perhaps, even more interesting. Those that have been described consist of some portions of the breast-bone and the sacrum, of a species referred by Prof. Owen\* to the family *Vulturidæ*. They indicate, however, a smaller species of Vulturine birds than is known to exist at the present day, and one which probably belonged to a distinct sub-genus.

In the Miocene and Pliocene formations, the eggs of birds have sometimes been found fossil, as at Auvergne and Ascension Island; but the indications of this great division of the Vertebrata are exceedingly few and imperfect. Their absence in these more recent strata renders it highly probable that a similar reason (that of the

Pliocene period. This species is figured at the close of chapter xxxviii, but differs too little from the common species of our own country to require any detailed description.

\* Geol. Trans. 2nd Ser. vol. vi. p. 208.

rarity of favourable circumstances existing for their preservation,) may have prevented their being more frequently exhibited in the Chalk, the Weald, or other members of the Secondary group.

The singular abundance of the remains of quadrupeds, in the gypsum quarries of Mont Martre, is a fact scarcely paralleled in any similar formation; and as by their means it was that the attention of Cuvier was first turned to the study of Palæontology, they are far too interesting even in this respect to be omitted in any description of Tertiary fossils. Fragments of similar animals have also been found, though rarely, in some parts of the London Clay formation, and in some of the valleys of the Jura and other localities of the Miocene period. In the Paris Basin the skeletons are usually isolated, and often entire, but in other localities only broken fragments appear. About fifty species have been determined all extinct, and nearly four-fifths of them belonging to a division of the order *Pachydermata* which is now represented by only four living species, three of them tapirs. The remaining fifth part comprises a few carnivorous animals and Rodents, besides one bat and an opossum.\* My account will be chiefly confined to those species which belong to the order *Pachydermata*.

Of these the two genera, *Palæotherium* and *Anoplotherium* are those which contain the largest number of

\* I have already mentioned that indications of a monkey (consisting, however, only of a tooth), have been found associated with those of an opossum and a bat, at Kyson in Suffolk, in strata supposed to be of Eocene date. It is thus proved that the most highly organised of the mammals next to man were living in northern latitudes at the very commencement of the Tertiary period, while the discovery also of similar remains in Miocene beds in France, and in Tertiary strata in India and Brazil, indicate that they were by no means confined to one locality, or one part of the Tertiary period. See Owen's *British Fossil Mammalia*, p. 1.

species, and which are in all respects the most singularly characteristic of the early Tertiary period. The former genus may be considered to be intermediate in structure between the Tapir and the Rhinoceros, while the latter takes its place rather between the Rhinoceros and the Hippopotamus, being, however, an animal of far less massive proportions than either, and indicating some curious analogies with the Camel. All the species of Palæotherium are nearly alike, differing chiefly in dimensions, but the Anoplotheria are separated into three distinct groups, in which not only the height, but the proportionate length of the bones of the foot and the tail differ very considerably.

The Palæotherium, of which there are twelve species described, varied in dimensions from the size of a rhinoceros to that of a hog, and the animal appears to have lived like the *tapir* of North America and Asia, in a swampy district, feeding, as its congeners still do, on coarse vegetable substances. It had a short fleshy trunk, as is evident from the structure of the nasal bones; the feet were three-toed, but in the fore-feet the first and last toe were rudimentary. The general character of the bones of the extremity indicates a close approximation to the *tapir*, which the animal, no doubt, chiefly resembled both in its proportions and habits.

Only six species of the genus Anoplotherium\* were determined by Cuvier, but these he found it necessary to separate into three groups. The species vary in size from the dimensions of a dwarf ass to those of a hare.

The first group of Anoplotheria includes two species, the most typical of the genus. One of these being much

\* So called from their having no canine teeth or tusks, and in this respect being unarmed (*ανα* privative, *ουλα* arms, *θηριον* a beast).

more common in the Paris Basin than any of the rest, was called *A. commune*, but the relative abundance of its remains is most probably owing to its aquatic habits. It attained a stature of from three to four feet, but its most remarkable peculiarity is its tail, which was nearly three feet long, while the total length of the animal must have been about eight feet. In proportions and general appearance, it seems to have resembled the otter, and it probably inhabited marshy places, and frequently repaired to the water in search of roots and succulent leaves of aquatic plants, upon which it fed. In its habits, in the shortness of its ears, and in the half naked skin with which it was covered, it probably resembled the hippopotamus and other aquatic pachyderms.\*

Another species of *Anoplotherium* (*A. gracile*) seems to have differed very essentially, not only in size and proportions, but in general appearance and habits, from the animal just described, and the slender gracefulness of the bones of the skeleton reminds one more of the structure of the gazelle than any other known quadruped. The description given by Cuvier of this species is a remarkable instance of the perfect idea he formed to himself of the living condition of an animal when only a few bones of the skeleton remained on which to base his conclusions.

The height of this animal, he observes, was about that of the chamois, for although the bones of the trunk

\* Cuvier remarks of this species, "Aucun quadrupède connu n'a la queue de cette grosseur et de cette longueur, si l'on en excepte le kangourou; et c'est encore la un caractère à ajouter à tous ceux qui font de l'*Anoplotherium* l'un des êtres le plus extraordinaire de cet ancien monde dont nous recueillons si péniblement les débris."—*Ossements Fossiles*, 4th Ed. vol. v. p. 385. The tail is composed of at least twenty-eight vertebræ, and equalled, if it did not surpass, the length of the body.

were considerably smaller, and the head scarcely equal in size, the extremities are excessively elongated, and in proportion as the movements of the species first described (*A. commune*) must have been heavy and ungraceful on land, this one, on the other hand, would be full of agility and grace. Light and elegant as the gazelle, it would course rapidly along on the banks of those marshes and lakes through which the other would swim, and would feed on the aromatic herbs, or browse on the young shoots of the shrubs growing in such localities. Its movements would be free, for it was not embarrassed like the larger species by a long tail; but, like the active herbivora, it was probably a timid animal, and therefore provided with large and very moveable ears, readily turned in any direction at the slightest approach of danger. Finally, there can be little doubt but that it was covered by very short hair, and, consequently, we only want to know its colour to paint the animal as it formerly appeared when a living inhabitant of the country where now, after so long a time and so many revolutions and changes, a few scattered bones only remain to attest its existence.

The smaller Anoplotherium (*A. leporinum*) belongs to a distinct group (*Dichobunes*), and seems to have resembled the hare, not only in dimensions, but in the proportions of its limbs, which are so constituted as to give it the same strength and swiftness, and the same power of rapid motion.

Another small Pachyderm has been determined from some bones found in the London Clay, and seems to have still more resembled the Hare; the eye being very full and large. This genus is named by Professor Owen *Hyracotherium*, and nearly approximates to another,



also exceedingly rare, called *Chæropotamus*, met with in the Paris Basin.\* Several other genera have been from time to time described from the older Tertiaries, but they are not so different from existing animals, as to call for detailed description.

In the beds of the middle Tertiary period there are found occasionally the bones of Mammals resembling those of the Paris Basin, together with others belonging to more recent periods, and in the Miocene beds of the valley of the Rhine at Eppelsheim, more than thirty species of fossil mammalia have been determined, one of them of very large size, and exceedingly remarkable structure, to which the name *Dinotherium* has been given.

The *Dinotherium* is the largest of the terrestrial mammalia of whose existence we have any positive knowledge, but as it is not a matter of absolute certainty at present of what nature its extremities may have been, we are hardly in a condition to speak very decidedly of its general appearance or habits. It is chiefly known by fragments of the head and teeth, which exhibit a near approach, the former to the Cetacean tribe, and the latter to the Tapir, but there is a remarkable and very striking anomaly in the existence of two large and heavy tusks placed at the extremity of the lower jaw, and curved downwards, like the tusks in the upper jaw of the Walrus. It is probable, from the size and position of these tusks, as well as from the structure of the bones of the head,

\* Both these extinct genera are probably more nearly allied to the recent *Hyrax* than to any other of the Pachyderms. This animal, the *Hyrax*, sometimes called "Daman," is a native of Africa and some parts of Asia; it is of the size of a rabbit, the muzzle and ears are short, the hoof is very small, thin, and rounded, with the exception of the inner toe of the hind foot, which is short. It is covered with hair, and inhabits the rocks, frequently becoming the victim of birds of prey.

that the animal was aquatic in its habits, living almost entirely in the water, and feeding on such succulent plants as it could there obtain.

The length of the Dinotherium is calculated to have been at least as much as eighteen feet, and its proportions were, probably, very much the same as those of the great American Tapir. It was provided with a trunk which seems to have been short, but extremely large and powerful, and capable of being employed to tear up the food which the tusks, acting like pick-axes, may have loosened. The structure of the scapula, or shoulder-blade, a specimen of which was found supposed to be referrible to this animal, seems to indicate an adaptation of the fore-leg to the purposes of digging, and it appears to correspond with the peculiarities in the structure of the teeth and lower jaw. It is not unlikely from the structure of some other extinct Pachyderms, that the very anomalous position of the tusks has reference to other peculiarities of dentition of the Dinothere, and that this animal forms a remarkable link connecting the Aquatic Mammalia of large size with the large land Pachydermata, by means of another and also extinct genus, the *Mastodon*, whose remains are found in Europe in strata of the newer Miocene and older Pliocene period. The remains of *Mastodon*, however, being much more abundant in North America than in any other part of the world, and occurring there in deposits of a very recent date, a description of that genus must be deferred to a future chapter.

The newer Tertiary strata of Europe often contain bones of large quadrupeds, and the Norwich Crag abounds with the remains of Elephants, and large ruminants of the Deer and Ox tribe, from the abundance of which indeed the name Mammaliferous Crag was suggested by

Mr. Charlesworth. I shall not now describe these extinct species, because they are also found in the diluvial deposits of gravel, a consideration of which will be the subject of another chapter. They belong, for the most part, to animals of which the same genus is still represented, although in other countries, and often in very different climates, but some of them are referrible to species not even locally extinct, or so nearly allied to those which now inhabit the same district, as to indicate clearly the small amount of change that has taken place since they inhabited our island.

A gigantic beaver (*Trogotherium*), and an equally gigantic mole (*Palæospalax*) have both been found associated, it is said, with bones of the common otter and one or two other still existing species of mammals, in the newer Tertiary formations in England, proving,—if the age of the deposits that contain this mixture of fossils is accurately determined,—that no great changes can have taken place in the climate of our island since the Miocene period, and, at all events, that there have been no such alterations or modifications of the land as should necessarily involve the destruction of all its inhabitants. I shall take occasion to recur to this subject when speaking of the animals whose remains are found in the gravel.

## CHAPTER XLI.

THE TERTIARY DEPOSITS OF ASIA, AND THE FOSSIL REMAINS  
FOUND IN THEM.

It is to be regretted that, even up to the present time, there is a great paucity of materials from which to describe, in a satisfactory manner, the Tertiary Geology of Asia; and even with regard to the English dependencies there yet remains much to be recorded before a general account can be given of the Geological structure of India. Notwithstanding this meagreness of detail, I shall endeavour, in the present chapter, to give a short abstract of Asiatic Tertiary Geology; but the materials are so scattered, and the districts that have been carefully examined and described so distant and unconnected, that I must be excused if I cannot succeed in producing a continuous narrative, or if the subject is less distinctly made out than its importance deserves. My account, commencing with a description of the Tertiary beds of Asia Minor and the Caucasus, will be found to include the principal phenomena presented in the Indian Caucasus and Northern Persia. It will, in that way, conduct the reader to the valley of the Indus, and thence to the singular district forming the province of Cutch. I shall then retrace my steps, and give a short account of the Tertiaries of the Sewalik Hills, and also of the similar deposits in the Northern provinces, and conclude with a notice of the Geology of Central India, between Bundelkund and the Mysore. Of the

Chinese Empire and Tartary, and the islands on the Eastern and Southern Archipelagos, I cannot pretend to give any account whatever, as I am not aware that any observations have hitherto been recorded by which we may obtain a notion of their true Geological position among stratified rocks.

Beginning then with that part of Western Asia on the borders of the Mediterranean, I have first to describe a considerable Tertiary deposit, of fresh-water origin, which occupies a large portion of the surface of Asia Minor, and consists, in general, of calcareous marls and white limestone, the latter greatly resembling chalk, and containing flints, but sometimes more compact, and not unlike the lithographic limestone of Solnhofen.

These lacustrine strata are, for the most part, nearly horizontal, and they are found in almost every large valley, but not in the narrow ravines of the mountain chains. They are very often barren of fossils, but sometimes contain the remains of land and fresh-water shells and portions of vegetables.\*



GENERAL SECTION ACROSS THE DISTRICT OF SMYRNA †

The principal locality of these deposits in Asia Minor seems to be in the neighbourhood of Smyrna, where the Tertiary limestone forms an extensive table-land, and abuts unconformably against the Hippurite limestone and micaceous schist. In some parts of this district, gravel,

\* Geol. Trans. 2nd Ser., vol. vi. p. 17.

† 5. Modern alluvium.

4. Trachyte.

3. Lacustrine gravel.

2. Lacustrine limestone and marls.

1. Hippurite limestone.

resembling the ancient drift of England, both overlies and alternates with the marls which are there associated with the newer limestones, and a stratum of trachytic rocks, produced by the sudden eruption of volcanic matter during the Tertiary period, forms a remarkable feature in the country, overlying, in some places, the sedimentary rocks.\* The diagram exhibits the manner in which the Tertiary strata have been affected by this outburst of volcanic matter, and the singular way in which the Tertiary beds dip *towards* Mount Pagus,† which, however, has been erupted since their deposition. In some other basins of this district, the lower beds of the Tertiaries are made up of volcanic ashes, several feet of which are interposed between the white limestone and the Secondary rocks on which they rest unconformably.‡

Volcanic phenomena, exhibited in Asia Minor on a grand scale, and there modifying the physical features of the country, have produced effects still more striking on the borders of the Black Sea, and between that and the Caspian. The intermediate land, which forms, in fact, the Chain of the Caucasus, is raised to the height of 10,000 feet above the sea, and on each side of these lofty mountains, which consist chiefly of newer Secondary rocks, there are Tertiary basins of very considerable extent. The recent researches of M. Dubois in this dis-

\* Geol. Trans. 2nd Ser. vol. v. p. 295.

† This hill rises immediately to the south of the modern town of Smyrna, and its height is about 500 feet.

‡ The observations of Mr. Hamilton on the central and eastern part of Asia Minor, would seem to shew the probability that there is of the white limestone beds which form the central plain of Asia Minor, being of lacustrine origin, and referrible to the Tertiary period. This whole district, however, has been the scene of such frequent and violent disturbance in modern times, that little beyond conjecture can be offered upon the subject, at all events until the beds are examined more thoroughly than they have been at present. (See Geol. Trans. 2nd Ser. vol. v. p. 583, *et. seq.*)

trict (which is, probably, very near the spot where man was first introduced upon the earth) cannot fail to interest every one who would connect the early history of our race with some of the most recent Geological phenomena;\* but I cannot indulge here in such speculations, nor have they anything to do with the simple outline I am endeavouring to give of the actual phenomena as they have been observed.

The western shore of the Caspian sea abounds in Tertiary deposits, contemporaneous with those on the eastern flanks of the Caucasus, but differing somewhat in mineral character, and consisting of a series of limestones, the lowest of which is of considerable hardness, but full of cavities containing calcareous spar. This lower limestone is of a grey colour, has a splintery fracture, and contains no fossils, and it is succeeded by another bed, which is more compact, and contains fossil shells partly crystallized, while other beds of the same kind overlie these, the uppermost of all being porous and covered by loose sand, which is succeeded by calcareous marl. The whole group seems to bear marks of having been formed in a volcanic district, and is evidently of lacustrine origin.

All along the eastern shores of the Caspian, the same Tertiary limestone occupies a prominent place, and is developed to a great thickness, the lower part being non-fossiliferous, or nearly so, while the upper beds consist almost entirely of bivalve shells (*Cardium*, *Mytilus*, *Venus* and *Donax*), which are so close together that they actually compose the mass of the rocks. The beds are, for the

\* M. Dubois' speculations have reference to the probable draining of some of the extensive lakes, which, till a comparatively recent period, must have covered this part of Asia; and he seems to imagine that the sudden elevation or depression of some part of the mountain chain of the Caucasus may have produced a deluge, universal so far as man was concerned.

most part, horizontal and undisturbed, but, upon the coast, vast blocks of limestone are thrown together in wild confusion, and appear to have been torn asunder and thrown down by means of some great convulsion.\*

A soft limestone of greyish black colour, is mentioned also as often overlying the shell limestone just described. Some of the fossils found in this bed offer evidence of the former union of the Black Sea and the Caspian, and the uniformity of the limestone deposit over so large an extent of country, reaching as it does into Persia and extending into Tartary, would certainly seem to favour this idea.†

Between the Caspian Sea and the river Oxus a sandy desert intervenes, and the country is generally flat, rising, however, in a very gradual slope towards Caubul and the mountains called the Hindoo Koosh, a prolongation of the Himalayans westward of the Indus. The lower passes of this mountain range consist, principally, of light brown splintery limestones of great hardness; but their identity with the Tertiary limestones of the banks of the Caspian has not been shown. On their southern flanks in the province of Caubul, there is a beautiful white marble found, but no account has yet been given of its Geological position. Further on towards the south are numerous narrow defiles, first of sandstone and then of mica schist; but both the Punjaub and Lahore are generally flat, the country consisting of indurated clay, which

\* The southern shores of the Caspian are chiefly composed of igneous rock, forming a mountain range, and on the southern flanks of this range, near Tehran, beds of compact fine-grained lithographic limestone have been described, which extend over an immense tract to the north and north-west of Tehran, and are ultimately seen to rest upon shales and red sandstones, which overlies compact limestone. The limestone is supposed to be contemporaneous with the carboniferous limestone of Europe. (Dr. Bell. Geol. Trans. 2nd Ser. vol. v. p. 577.)

† M. Eichwald, Edin. New. Phil. Journ. for 1832-3, pp. 122 and 324.



is sometimes gravelly. After the rivers of the Punjab have entered the Indus, that river continues its course through a flat district, but at Hyderabad there is a finely grained shelly limestone, probably the same as that which occurs in Cutch. Nummulites are found in a ridge near the right bank of the river, and they must, probably, be referred to the Tertiary period.\*

The province of Cutch, which we have next to consider, is a hilly and rocky district united to the main land of India by an area of upwards of 7,000 square miles, which can neither be considered land nor water, being usually in the condition of a sandy flat totally devoid of vegetation, but it is overflowed entirely during the monsoons, and at that season is only passable on camels. This singular district is called the Runn of Cutch.

The nummulite limestone of Cutch, no doubt of the same age as the similar bed above alluded to, occupies an elevated tract on which the town of Luckput stands, and it thence extends southwards for some distance. It consists of a mass of small nummulites and other fossils, resembling those of the English and French Tertiaries; and some of the river banks present perpendicular sections of solid rock from sixty to seventy feet in height, entirely composed of small fossil foraminifera. The stone has much the appearance of chalk, and the beds are horizontal, except where they have been disturbed by recent elevations, which are very frequent in the district.

Overlying the nummulitic strata, there is found a hard argillaceous grit, interspersed with fossil shells, and covered by beds of pebbles or conglomerate. In many places towards its northern limits, this bed rises into hills and considerable tracts of high undulating country, the loftier

\* Sir A. Burnes. Geol. Trans. 2nd Ser. vol. iii. p. 491.

portions consisting invariably of hard shelly rock, and including large patches of silicified corals. The Tertiary deposits reach to a distance of thirty miles from the sea, and extend in a belt of about a third of that breadth throughout the whole southern coast of the province. The fossils also on the immediate shores of the Runn, and of the islands in it, are of the same Geological period.\*

The great granitic and metamorphic district of India, the mineral axis of the country, if such it can be called, appears to run very near the western coast of the Peninsula, and is everywhere close to the surface, being often covered by little more than extensive beds of alluvium. The Tertiary beds of Cutch do not seem to cover the low granitic platforms on the opposite coast of Gujerat, either to the east or south, and their only representative is a rock locally called *Kunkur*, which is very extensively distributed, and seems to be a general name for all irregularly deposited beds in which calcareous matter is found.

The Kunkur is more especially abundant in the line of country running up from Gujerat to the north-east, towards Delhi, and is constantly observed not only occupying the low ground, but reposing under the vegetable soil of the elevated plains and plateaux of central India, and even on the summits of hills between two and three thousand feet above the level of the sea. The Kunkur, however, is not stratified, and belongs rather to diluvial than to Tertiary deposits.

It appears extremely probable, if not certain, from the observations of Mr. Hardie,† that the lacustrine limestones found in Cutch, and on the banks of the Indus, are repeated in the more central province of Mewar,

\* Capt. Grant. Geol. Trans. 2nd Ser. vol. v. p. 300.

† Edin. New Phil. Journ. 1832-3, p. 263.

where two lakes of considerable extent, and several tarns, or smaller pools, must be still forming very similar deposits.

These lakes are all greatly enlarged during the rainy season, and they would appear to have been formerly much more numerous and extensive than they are now, the general structure of the country greatly favouring the idea that they have been drained by a channel opened for them during some violent natural convulsion. The craggy ridges and deep ravines in the table-land of Oodipoor exhibit, indeed, in many places, distinct evidence of such disturbances, by the sections of strata exposed in the sides of several picturesque gorges, which probably permitted the escape of the water of those ancient lakes in which the strata were deposited, and of which the actual outlines can occasionally be traced.

The strata still further to the north-east, between Mewar and Delhi, appear to belong to formations of a much older date than the Tertiary period,\* and these, probably, extend through a great part of the province of Delhi, although covered up for more than a hundred miles to the north by fine sandy soil and kunkur. Beyond this (at Seharunpore) the Tertiary beds of the Sewalik range commence, and may then be traced towards the south-east, on the flanks of the Sewalik hills, to a very considerable distance.†

\* Edin. New Phil. Journ. 1832-3, p. 77.

† Rev. R. Everest. Geol. Proc. vol. viii. p. 567.

The Sewalik hills lie at the foot of the great Himalayan chain, with which they are sometimes connected by a succession of low mountains, and sometimes separated by valleys from three to ten miles in width. They extend from the Sutluj river, almost without interruption across the north of India to the Burham-pootur, and the usual heights to which they attain do not exceed from two to three thousand feet. They are crossed at various points by most of the numerous tributaries of the Ganges.

I am entirely indebted for these and other details of the Geology of the

The formations composing these hills, which have sometimes been called the Sub-Himalayans, consist of beds of boulders or shingle, of sands hardened to every degree of consistency, of marly conglomerate, and of an infinite variety of clays. The strata dip from  $15^{\circ}$  to  $35^{\circ}$ , generally towards the north, and the breadth of the inclined beds is from six to eight miles.

In that part of the Sewalik district west of the Jumna, there is an interminable series of clays and sandstones, the former being in greatest abundance, and the whole dipping at an angle of  $20^{\circ}$  to the north, and extending to the plain of the Jumna.

Chiefly in the upper part of this series there occurs a sandstone rock, which is generally soft and containing but few fossils, but in some parts extremely fossiliferous, and in that case so hard as to turn the edge of the chisel, protecting the fossils from destruction, even when they are rolled as boulders along the beds of the mountain torrents. Fossil bones have been found also in great abundance on the surface of the slopes near the sandstone, and amongst the ruins of fallen cliffs; they include several genera of Pachydermata, Carnivora, Ruminantia, and even Quadrumana, besides the bones of Crocodilian animals and Tortoises, many of them extremely remarkable, and indicating the former existence in this part of the world of races of animals very different from those now inhabiting the district. Most of the species are new, and there appears to be scarcely a limit to the variety, as well as the abundance, of these remains.

Sewalik range, to Capt. Cautley's valuable memoir in the fifth volume of the Geological Transactions, 2nd Ser. p. 267, and to Dr. Falconer's manuscript notes. To the latter gentleman I have to express my great obligations for his kindness and readiness in communicating information.

\* Geol. Trans. 2nd Ser. vol. v. p. 537.

The hills of the Sewalik range, between the Jumna and the Ganges, consist of alternations of sand and clay similar to those just described; but these are overlaid by beds of shingle of enormous thickness, which also alternate with the sandstone. Carbonaceous matter occurs (sometimes in the form of lignite) throughout the sandstone, and the trunks of dicotyledonous trees are found in great abundance. Marls, also, are here associated with the upper beds, and contain, like the upper sandstones to the west, vast multitudes of fossil remains, chiefly of Mammalia and Reptiles. These fossils are remarkably perfect, and are usually of a deep black colour, owing to the presence of hydrate of iron. The greater part of them have been obtained from a deposit in the Kalowala Pass.

The Tertiary strata of the Sewalik hills have not been traced south of the Ganges, in any beds which can be proved to be contemporaneous with them. An immense formation of basalt, extending over more than 200,000 square miles of country, has concealed or altered all the stratified rocks from beneath which it has forced its way,\* and occupies nearly the whole of the eastern part of the Deccan, stretching into the adjacent provinces of Malwa and Bundelkund. Granite and gneiss extend to the south-east of the basaltic district, and the same rocks occupy a considerable tract to the north and north-west, so that there seems scarcely a vestige of any fossiliferous deposit throughout the wide tract of country which intervenes between the distant provinces of Delhi and Mysore,

\* Geological Transactions, 2nd Ser. vol. v. p. 537. The paper here referred to is one of those valuable communications for which the scientific world is indebted to the late J. E. Malcolmson, Esq. M.D., a gentleman whose recent and sudden death is an event which cannot but be deplored as one of the greatest losses that could have happened to the progress of scientific research in India.

with the exception of certain detached patches of lacustrine limestone, described by Dr. Malcolmson in the paper already alluded to.

The great sandstone formations of the south and north of India, containing the celebrated diamond mines of Golcondah, and a number of limestones and schists associated with them, exhibit everywhere the same characters, from the latitude of Madras to the banks of the Ganges.\* Overlying these and often embedded in red chert, in the basaltic district, there have been found silicified shells of fresh-water animals, and masses of hard coarse chert, consisting almost entirely of Gyrogonites. A regularly stratified rock is also met with in the same localities, formed of compact whitish chert, and containing the same kinds of fossils associated with the remains of Paludinæ.

These beds are chiefly exhibited in the precipitous descent of a mountain range, and similar beds have been found at several points in the centre of India, as at Saurgur, Jubbulpoor, in the great range which separates the Deccan from the north-western part of Hindoostan, and at several points on the river Godavery, even to the coast near Masulipatam.†

I am aware that this attempt to describe the Tertiary Geology of India must be extremely imperfect, although I have availed myself of all the information I was enabled

\* These beds, although they are for the most part horizontal, are of older date than the erupted basalt, and were supposed by Dr. Malcolmson to belong to the more ancient Secondary, or the Palæozoic period. The argillaceous limestone appears at the surface as a compact rock, thinly bedded, and often intersected by vertical partings. Some specimens would form an admirable lithographic stone, were it not for the presence of small crystals of quartz.

† Geol. Trans., 2nd Ser. vol. v. p. 572.

to obtain. It may, however, by attracting the attention of scientific observers in India, induce some one to undertake the task who is better qualified to do so than myself, and it is a matter of considerable importance, and may be even looked upon as the first step towards an accurate geological survey of the English dependencies under the superintendence of government. Until some general notion of the structure of the country has been arrived at, such a measure will hardly be undertaken, nor would it be altogether advisable; for in matters of this kind there must always be many preliminary attempts, and imperfect generalisations. I am anxious, however, to be understood as not in the slightest degree depreciating the value of the numerous, accurate, and most useful observations that have been already made and recorded. I only wish that others, who may have the opportunity, may be induced to proceed in the same course, and that they should do so with some idea of what has been effected by those who have preceded them, and of the nature and extent of the work which still remains to be done.

It is chiefly in Northern India, and in that part of the continent marked by the Sewalik or Sub-Himalayan range of hills, that the Asiatic Tertiary strata have yielded any extensive supply of fossil organic remains. There, however, the abundance and variety of these remains is so great, that, perhaps, hardly any formation, or group of formations, hitherto examined in any part of the world, can exhibit the like; but the fossils consist chiefly of the remains of large land animals, associated with a few fragments of large fresh-water fish.

It is not easy to decide whether these remarkable fossils belong to one geological epoch, or whether they

represent the inhabitants of the earth in Central Asia, through a very large part of the whole Tertiary period. The strata in which they are most abundant, extend for a distance of 200 miles, being inclined, for the most part, at a high angle, and elevated into hills 3,000 feet above the sea. They are, moreover, of great thickness. The fossils include the oldest genera of Pachydermata (those found in the Eocene beds of the Paris Basin), associated with the Giraffe, the Hippopotamus, the Horse, the Camel, the Antelope, and the Monkey, while other species, referrible to new genera, have also been determined. And not only so:—The older and extinct genera of Pachyderms are here found in strata apparently but little removed from others in which Reptilian remains occur, belonging to species identical with those which still inhabit India, but associated with a Tortoise of the most gigantic proportions, measuring, probably, nearly twenty feet on the curve of the carapace !\*

\* Remains of this, and of an almost incredible multitude of other vertebrated animals from the Sewalik Hills, are now in the British Museum, having been presented to the British nation by Captain Cautley. Captain Cautley, Dr. Falconer, and others, have been for many years engaged in the north of India, following out with the utmost spirit and energy, and at great expense, a series of Geological investigations connected with these fossils. The collection presented to the museum is certainly a most remarkable monument of perseverance and research ; and some idea of its magnitude may be formed from the fact, that it was contained in upwards of 200 packing cases, the average weight of the contents of each of which was about four hundred weight. The nature of the contents will be understood from the text. Besides the collection made by Captain Cautley, there is a series of selected specimens belonging to Dr. Falconer, contained in fifty similar chests ; a large collection presented to the Edinburgh University Museum, and two or three others, all of which are, at the present time, in a condition to be made use of for scientific purposes. It is greatly to be desired, that collections, so unrivalled in extent, and presenting so much new matter of the deepest interest to the Zoologist and the Geologist, should be immediately made available by the publication of descriptions and figures of the new species. At present no account whatever has appeared of the great majority of them, and even of the new genera only a few detached memoirs have been published in the Transactions of scientific bodies.



But to proceed with the description of the fossils in something of the order hitherto adopted, it is worthy of remark, in the first place, that but very few remains of invertebrated animals have hitherto been brought to light from these localities. What there are consist chiefly of the shells of land and fluviatile mollusca, and of fresh-water crustacea; and, from the invariable absence of marine remains, it is clear that the whole must have been deposited from some vast inland sea of fresh-water, receiving for a succession of ages the transported sand and mud brought down by many streams from a considerable extent of land. Several undetermined species of birds, chiefly Waders, have been met with, and, as I have already mentioned, numerous species of fish which belong to the family of *Siluridæ*, and are allied to existing types; but these, like the remains of invertebrata, are comparatively rare, and are far outnumbered by the Reptilia and the Mammals, which in other formations are seldom preponderant.

The Reptiles of the Sewalik Hills include a great number of extinct species, many of them presenting remarkable peculiarities of structure; and amongst the number are several Crocodiles, some of them larger than any living animals of the kind. But the vast Tortoise I have already alluded to (*Megalochelys atlas*), is, beyond all measure, the most extraordinary of these ancient inhabitants of Asia, and its discovery almost justifies the wildest dreams of Hindoo mythology.

Of the Mammalia, most of the orders still represented on the continent of Asia, exhibit here some extinct species. There are, for instance, the remains of several *Quadrumana* (Monkeys), in most cases indicating animals of large size, and of several new and very remarkable

species, both of *Rodents* (gnawing animals) and *Insectivora*, one of the latter being much larger than any existing species of the order.

Several new and singular forms of the different families of *Carnivora* have also been determined from among these fossils; and a colossal Bear, a new genus allied to the Otter but as large as the Indian Panther, numerous species of *Felidæ*, and several of *Canidæ* and *Hyæna*, help to swell the list of the Sewalik fauna.

But of all the different orders, none is more fully represented, or presents a more interesting group of transition species, than the *Pachydermata*. Of these I can only give a very imperfect list, but it will enable the comparative anatomist to form some notion of the unequalled riches of the district in which these collections were made. The *Pachydermata* include two species of *Mastodon*, one of which is new, and indicative of a passage to the Elephant; there are two new species of Elephant, several new species of *Rhinoceros* and *Hippopotamus*, a considerable number allied to the Pig but all undescribed; three species of Horse all new, and one of them of small size and of the slender and graceful proportions of the Antelope; an undescribed genus connecting the *Hippopotamus* with the *Ruminants*, and several species of the *Eocene* genera, *Anoplotherium*, *Anthracotherium*, and (probably) *Palæotherium*.

The *Ruminants* include two new species of Giraffe, and a third species indicating an animal nearly allied to the Giraffe, if not of the same genus; two new Camels, and a multitude of hitherto undescribed species of the genera *Bos*, *Bubalus*, *Cervus*, *Antelope*, *Moschus*, &c., comprising thus almost every type in this extensive family; but besides these, there is also a new genus of a very

anomalous kind, which has been described by Dr. Falconer and Captain Cautley, under the name *Sivatherium*.\*



SIVATHERIUM GIGANTEUM. FAL. AND CAUT. (SKULL.)

The *Sivatherium*, which appears to have been a ruminating animal, having many strongly marked approximations to the *Pachyderms*, must have attained a very large size, surpassing even that of the *Rhinoceros*. The remains originally discovered consisted of a cranium, nearly perfect; and the appearance of this part is so strange, and even grotesque, as to strike one with surprise at the first glance. The head is of large size, nearly as large, indeed, as that of the elephant, and enormously developed in the hinder portion of the cranium behind the orbits of the eye. The facial part is exceedingly wide and short, and from the structure of the nasal bones

\* Asiatic Researches, vol. xix. p. 1. Geol. Trans. 2nd Ser. vol. v. p. 503.

and other peculiarities in the anatomy, it is concluded that the animal was provided with a large upper lip, probably expanded into a short proboscis or trunk, like that of the tapir.

Not only in the proportionate size of the head and in the possession of a trunk, but in the general appearance of the skull, the Sivatherium seems to have greatly resembled the Elephantoid animals. The orbit of the eye is considerably smaller in proportion than in most Ruminants, and it is placed more forward and lower. We may, therefore, infer that the eye was small, and not prominent, and the expression of the face dull and heavy, and also that the limits of the direction of vision were so far forwards as to prevent the animal from seeing, except straight before it.

But this head so closely resembling that of the larger Pachyderms, was provided with two distinct pairs of horns: one pair being placed between and above the orbits, and the other pair behind them. Both pairs of horns were attached to smooth cores, like those of the ox and the antelope, and the horny sheaths, which are not often preserved, were of very large size.

The structure of the teeth in which the reference of the animal to the Ruminantia is distinctly indicated, exhibits also some anomalies probably adapted to peculiar habits of the species. It has been inferred, from the nature of the grinding surface, that the food of the Sivatherium was less herbaceous than that of existing horned Ruminants, and derived rather from leaves and twigs than from grass; or that, as in the horse, the food was more completely masticated, the digestive organs less complicated, the body less bulky, and the necessity of regurgitation from the stomach less marked.

On the whole, then, this very remarkable animal, one of a large group of extinct genera, formerly existing in Northern India, seems to fill up a most important gap in Natural History. It was a Ruminant, possessing the characteristic structure of that class in the teeth and horns, while the osteology of the face, the expansion of the upper lip, and the small size of the orbit of the eye approximate it to the Pachyderms. With regard to the proboscis, although it may at first sight appear unlikely that a Ruminant should be provided with such a contrivance, yet we see an approach to it in the cleft upper lip of the camel, and it is not essential to the Pachydermata, but accidental to the size of the head and the habits of the animals in certain genera. Some others of the extinct genera from the same locality, exhibit the passage between the two orders in other ways, and even the dentition, in one new and small species of Hippopotamus, is found to have changed entirely from its most characteristic Pachydermal type to a condition scarcely determinable from that of the true Ruminants. It may fairly be anticipated, that the study of these fossils will tend to break down distinctions that have hitherto been supposed to exist between the different orders of Mammalia, not only with respect to the two orders now under consideration, but also many others.

## CHAPTER XLII.

THE TERTIARY FORMATIONS OF AMERICA, AND THE FOSSILS  
CHARACTERISTIC OF THEM.

THE Geology of the Tertiary formations has been studied in far greater detail, and under circumstances much more favourable for the elucidation of the subject in America, than has been the case even in those parts of Asia where no extraordinary difficulties are to be surmounted. The country also, generally, seems to exhibit more perfect analogies with European types ; and thus it happens that a tolerably detailed account has been given of the strata which it is the object of this chapter to describe.

It would, however, be quite in vain to attempt, within the limits of a single chapter, to give anything more than a very general notion of the American Tertiary deposits. It is true that they are, especially in the southern continent, singularly uniform in character over enormous tracts of country ; but in the great expanse through which they have been traced, there are necessarily so many changes, both in the strata themselves and in their fossil contents, that a considerable space would be required merely to allude to the more important of these differences. My object is not to dwell on such points, but to communicate a general notion of the groups of strata which, indeed, are scarcely equalled in extent by any system of formations in the Eastern Hemisphere.

The Tertiary strata in North America include some beds contemporaneous with the very oldest Tertiaries hitherto described, and commencing with these a tolerably complete series has been traced conducting to the newest Pliocene, and so to the recent period. All of these beds that occur in the United States (where they are chiefly developed), have been minutely described, and accounts of them published under the superintendence of government in the different states of the Union. Similar phenomena have also been observed in Canada, and a very large number of the most interesting localities throughout North America have lately been visited by Mr. Lyell, whose familiar acquaintance with the Tertiary Geology of most parts of Europe, admirably fits him for the task of bringing into one view the numerous phenomena connected with the structure of the Western continent. The Geology of South America has been the subject of an elaborate description by M. A. d'Orbigny, and many interesting facts concerning it have also been recorded by Mr. Darwin, and by M. Lund, a Danish naturalist.

The chief localities of the Tertiary deposits in North America are to be found in the eastern states of the Union, and the greatest development of the older beds is in Virginia, the two Carolinas, Georgia, and Alabama. In Virginia these beds consist of greenish sands, nearly identical in appearance with a portion of the Cretaceous series, and of the same mineral composition; and a little further to the south a continuous formation of white limestone occurs, which is of no great thickness, and which varies in hardness, and is composed of comminuted shells, but which resembles so closely certain

Cretaceous beds of the Secondary period in New Jersey, as to have been frequently mistaken for them, so that, in this way, great confusion has been caused in American Geology.

It appears, however, from Mr. Lyell's researches, that this resemblance does not extend to the fossil contents of the beds, and that there really is no indication offered of any transition from the Cretaceous to the newer period. The white limestone of the Tertiary period belongs, no doubt, to the lower part of the series, and differences appear to be traceable in the ages of the different Eocene beds; but there is, probably, no very distinctly marked series, and the great difference observable amongst the fossils that have been obtained from various localities is, probably, rather owing to differences in the circumstances of deposition than of age.

The Eocene green-sands of Virginia contain, in great abundance, some species of fossils which are not to be distinguished from species common in the London Clay (e. g. *Venericardia planicosta*, *Ostrea bellovacina*, &c.), and the sands are overlaid by clayey beds, which sometimes seem made up almost entirely of shells, many of them apparently identical with Suffolk Crag species, but a small proportion being still found in a living state on the coasts of America.

The white limestone already mentioned, and which was, probably, contemporaneous with the Virginian Tertiary green-sand, has been called "the Santee limestone," and is traceable for several miles (its upper surface being irregular, and covered with non-fossiliferous sand), until it is lost under a newer deposit of considerable thickness, consisting of clay and loam, alternating with



quartzose sand and beds of siliceous burr-stone.\* In other places the Eocene beds of limestone and marl rest on a Tertiary lignite which is interposed between the marls and the Secondary rocks, but no appearance of any passage beds between the two systems of formations has been traced, nor is it probable that any such exist at all in any part of North America. In the more southerly states, as Alabama, the Eocene beds consist of a dark-coloured fossiliferous sandstone, and beds of the same age, and of similar appearance, occur at intervals as far to the west as a place called Claiborne, on the Tombeckbe, a tributary to the Alabama river. Beyond this point they have not been traced.

The Virginian Tertiary green-sands, as also the Santee limestones, are overlaid by a considerable deposit of Miocene clay, abounding in fossil shells, and sometimes entirely made up of them; but the total thickness of these latter beds is not very great, nor has any considerable variety of species been obtained from among the fossils embedded: they are, notwithstanding, widely developed in horizontal range, being spread over immense plains but little elevated above the level of the Atlantic.

The most northerly limit of the Tertiary strata in the United States is in an island in the State of Massachusetts, called 'Martha's Vineyard,' where beds whose fossils indicate them to be of the Miocene period, consist of white and green sands and conglomerate, resting on lignite, and all the beds are inclined at a high angle to the north-east, and are well exposed in a vertical

\* This *burr*, or *Buhr*-stone, is a nearly pure siliceous rock in which calcareous and other matter, originally forming part of it, has been parted with and become replaced by silica, so that the casts of fossils are perfectly preserved in it, and even the species can often be identified.

section on the south-western extremity of the island. These deposits, which, besides being highly inclined, are often greatly contorted, are very fossiliferous, and contain bones of mammalia, chiefly those of Cetacean animals, which have been much rolled and rounded, as if by the action of waves.

Tertiary beds of the middle or Miocene period, occupy, it would appear, a very important place among the North American deposits. An extensive series, now determined to belong to this period, occupies nearly the whole surface of both shores of Chesapeake Bay, an area extending a hundred miles from north to south, and more than fifty miles in width, and the strata already mentioned as occurring in Virginia are scarcely less extensively developed. Throughout the former district, the beds lowest in the series are argillaceous, and the uppermost are sandy, while in both cases they are highly fossiliferous, and when seen on the side of a river they are sometimes found to consist of little else than shells and the remains of zoophytes, often in a high state of preservation. In Georgia, the beds of the same age are more loamy, and consist of sandy clays and sand, the latter often hardened into sandstone, and in this state they occupy a very important place in the Geology of the southern states, but in Alabama they are distinctly seen to rest on older Tertiary beds, which they only cover up occasionally.

The Newer Tertiaries of North America seem to belong chiefly to a very modern period, and extensive deposits are known to exist in several localities. Amongst these may be mentioned a series of clay beds with occasional alternations of sand, occurring at the mouth of the Potomac river in Maryland, which have been described by Mr. Conrad. In these beds, which are extremely fossiliferous,

all, or nearly all, the species of fossils hitherto described, are identical with those recent species found living on the neighbouring coast, the distance of which at present is as much as forty-five miles in a direct line. Similar beds occur at Niagara, in Kentucky, and in several other parts of North America, and the resemblance in all cases to recent deposits is very striking.

In South America, the Tertiary deposits are developed on a scale so extensive that the comparatively small proportion which such beds bear to the whole series of fossiliferous rocks in the Eastern world is completely reversed. The name 'basin' also is not quite applicable to them, as they form, for the most part, continuous groups of strata, having a dip quite as uniform as that of any of the Secondary or Palæozoic rocks.

It would appear from the researches of M. d'Orbigny,\* that the South American Tertiaries extend in an unbroken line from the great plain of the Amazons to the Straits of Magellan. From the mouth of the Plata southwards they occupy the whole space between the shores of the Atlantic and the Cordilleras of the Andes, and further to the north, they are found in the central provinces, having a breadth scarcely less considerable. They thus extend uninterruptedly for about 2,500 miles from north to south, and with a breadth which sometimes reaches 800 miles, and throughout this tract M. d'Orbigny has distinguished a subdivision into three groups, of which the lower includes a number of non-fossiliferous beds, which may be designated *the Guaranian series*; the next is of marine origin, and contains fossil marine shells, supposed to be of extinct species; it is called *the Patagonian series*; while the third or newest, is remarkable for the number of fossil remains

\* Voyage dans l'Amérique Méridionale, par M. Alcide d'Orbigny.

of mammals which abound in it, and which, although referrible to extinct species, indicate a very near approach to animals of the existing period. This latter bed is called the *Pampas clay*, and is covered by deposits evidently and unquestionably modern.

The *Guaranian series* usually consists of three groups of strata conformable to one another. The two lower of these groups are composed of ferruginous sandstones and marly limestones, of no great thickness or importance, and the upper bed is a gypseous clay, containing concretions, and is also ferruginous. They are all nearly horizontal, and the upper clayey beds being too nearly level to allow the water that falls on them to escape by drainage, immense marshes and innumerable small lakes are thus produced, and these form a remarkable peculiarity in the general aspect of the country.

The *Patagonian series* occupies a far more prominent position in the Geology of South America than the former. It is subdivided into two parts, the lower consisting of (1) marine beds of sandstone, with fossil shells of extinct species; (2) similar sandstones, containing the bones of mammals and fragments of fossil wood; and (3) gypseous sandstones and clay in the north, replaced by blue clays in the south. The upper part, both in the north and south, consists of an alternation of sandstones and limestones, overlaid by marine conglomerates; and these beds are characterised by identical species of organic remains on the two edges of the formation at a distance of more than 600 miles asunder.

These beds of the Patagonian group are not without considerable interest, and have already contributed many new species of fossil remains of mammals which are embedded in a hard sandstone, not allowing them to be com-

pletely extracted. Their most characteristic fossil, however, is a species of oyster (*Ostrea patagonica*), very extensively distributed in beds, the shells being in their natural position, and the two valves united. M. d'Orbigny, who has examined these South American Tertiary deposits, and compared them with those of other countries, has arrived at the conclusion that the whole of the two groups of formations, designated the 'Guaranian' and the 'Patagonian' belong to the *Eocene*, or oldest Tertiary period.

But M. D'Orbigny's view of the great antiquity of the South American Tertiaries does not seem to agree with the results of Mr. Darwin's investigations; nor is it rendered more probable when we examine the fossils obtained from the 'Patagonian' and compare them with those of the overlying 'Pampas Clay' formation. The latter bed appears to be of a date only just anterior to man's existence on the earth, and consists partly of gravel, and partly of a loamy clay, in which are found the bones of mammals, chiefly of extinct species, but identical with some of those determined from the supposed Eocene ossiferous sandstone on which the Pampas Clay rests.\*

The Pampas Clay, probably the formation most extensively developed in one spot of any hitherto described, is stated by M. d'Orbigny to occupy in South America a space of nearly 180,000 square miles. It consists of a single bed, of which the stratification is very imperfectly

\* This is the case, in some measure, with the *Torodon*, a very remarkable genus, nearly allied to the Rodents, or gnawing animals, and originally determined by Professor Owen, from specimens obtained by Mr. Darwin from the uppermost beds. Of this genus, one species (*T. paranensis*?) is stated by M. d'Orbigny to occur in the Patagonian sandstones. Voyage dans l'Amérique Méridionale, par M. Alcide d'Orbigny, Paris 1843, vol. iii., part 3, p. 71.

marked, and although in certain localities there are portions of the bed harder than the rest, and more or less sandy, these are apparently accidental, and not at all connected with one another.

This clay is only covered up by alluvial sands, containing shells of such fluviatile species as are still living at the mouth of the Plata.

The most remarkable and most interesting point with regard to the Pampas Clay, is the fact that abundant remains of mammalian animals have been found embedded in it, several of which have been referred to new genera. This being the case in a formation certainly of a very recent date, there has been some difficulty felt in determining the true geological position of the beds with respect to superficial deposits elsewhere. It appears, however, most probable, that the whole of the Pampas Clay is at least as recent as the gravel of Europe, and the consideration of its organic remains will therefore be more properly undertaken in a subsequent chapter, when I shall describe some of the organic remains found in the gravel and in contemporaneous deposits.

The fauna and flora of the Tertiary period in America present so few species that are strikingly different from those of the European Tertiaries, that the subject hardly requires more than a mere allusion in this place. The Older, or Eocene deposits in North America contain some molluscos remains, apparently identical with those found in the London Clay; and although, doubtless, many which are unknown in Europe are there common, there is little that admits of general description. The buhr-stone belonging to this period has been found, on examination under the microscope, to exhibit a texture similar to that of most flints, and seems to have formed upon sponges,

which were often, however, greatly decomposed before the silicifying process was completed. The infusoriæ in these and the newer beds have already been alluded to (see note, pp. 59, 60), and the greater number of the remains of Vertebrata belong to the newer period of the gravel, rather than to that of any regularly deposited Tertiary strata.

Among the fossils of this period there are, however, the remains of one species of considerable interest, and occurring in the older Tertiary deposits of North America. I allude to the Zeuglodon (*Basilosaurus*, Harlan), first described from several fragments found in the limestones of Alabama, one of the southern states. In the first account given of these fragments (which included portions of the jaw with teeth, several vertebræ, &c.), it was described as a Saurian, but it has since then been determined by Professor Owen to be unquestionably a mammal, referrible to the Cetaceous order, and probably allied to the Dugong, one of the herbivorous whales. The extremely colossal dimensions of the extinct American monster (reaching it would seem to upwards of 100 feet in length), the remarkably small proportionate size of the bones of the extremities, the dense structure of the ribs, and the extreme elongation of the bodies of the caudal vertebræ, all seem to render it probable that the Zeuglodon was one of the most extraordinary of the mammalia which the revolutions of the globe have blotted out from the number of existing beings.\*

\* Geol. Trans. 2nd Ser. vol. vi. p. 79.

## CHAPTER XLIII.

SUPERFICIAL DEPOSITS OF GRAVEL.—DILUVIUM AND ALLUVIUM.  
 —THE FILLING UP OF CAVERNS.—RECENT FORMATIONS OF  
 FOSSILIFEROUS SANDSTONE AND LIMESTONE.

THE regularly stratified deposits of whatever Geological period they may be, are, in most parts of the world, covered up, more or less, by a considerable mass of heterogeneous material derived from the degradation of the more ancient rocks. This mass is generally unstratified, and deposited in irregular heaps, partially filling up valleys, covering low tracts of level country and sometimes even capping low hills, but almost always bearing marks of having been transported from a distance over ranges of high land, although not without some reference to the present physical features of the country over which it has travelled.

Occasionally the fragments which have been thus conveyed are of large size and angular, and in this case they are called ‘boulders,’ or ‘erratic blocks;’ but such masses have not generally travelled to any very considerable distance from the parent rock. The transported fragments are much more commonly of small size, and rounded, as if by mutual attrition, at the bottom of the sea; and in this state they have been often carried to very great distances, and are found many hundred miles



from the place whence they seem to have been derived. They are then called 'gravel,' and are not unfrequently mingled with bones and fragments of bones of large quadrupeds. They sometimes also, but rarely, appear to be regularly stratified, and alternate with beds of fine sand and marl, containing the remains of land and fresh-water shells.\*

Superficial deposits of this nature, which apparently owe their origin to some more violent action than the ordinary force of river currents, are often spoken of under the general term of *diluvium* or *diluvial drift*, as having been caused, in all probability, by a torrent or deluge of water rushing over the land, tearing up the rocks in its passage, and conveying them to a great distance, rounding them and breaking them into fragments. It must not, however, be imagined that the effects observed can be accounted for by supposing only one extensive deluge to have passed over the country, for such an hypothesis is not at all sufficient, nor in any way satisfactory. But as I have already repeatedly expressed my determination not to discuss any points of theory in the present work, I here merely state the fact of the supposed nature of diluvial action to account for the use of the term *diluvium*, and the meaning of the word when applied to those transported masses of which gravel is the most generally known.

\* This is the case in the neighbourhood of Cambridge, and the phenomena have been described by Mr. Brodie in the Transactions of the Cambridge Philosophical Society (vol. viii. p. 138). It appears that, in this instance, there are two distinct beds containing land and fresh-water shells, the upper being a fine white sand, and the lower a hard white marl. They lie within a few inches of each other, and in a bed of fine sandy gravel, about fourteen feet from the surface, which also contains the bones of large mammalia (elephants, large ruminants, &c.) such as are usually found in the gravel of the middle of England. The fine gravel is the newest kind of diluvial drift occurring in the neighbourhood of Cambridge. A bed of coarse gravel underlies it, and the whole rests on, or is replaced by, what is locally called the *brown clay*.

The word Diluvium being employed then to designate the gravel, and such other material in which stones are embedded, and which appears to have been brought from a distance, it will be found convenient also to use, in contradistinction to it, the word *Alluvium* in speaking of the ordinary effects of fluvial action. The matter deposited in lakes and at the mouths of running streams consists partly, no doubt, of coarse fragments of rock and stone, but is more frequently in the condition of fine mud that has been long held in suspension in the water. The nature of the drift deposited by rivers, under ordinary circumstances in different countries, while it varies greatly in many points of detail, has yet a general and peculiar character, and can readily be distinguished from the deposits left after floods, and due to *Diluvial* action. Alluvium, as well as Diluvium, is thus a well-marked deposit, and its organic contents being chiefly confined to fluvial shells, and a few remains of land animals and vegetables, it is recognised without much difficulty, but is rarely an object of interest to the geological student.\*

In the present chapter the attention of the reader will be directed to the consideration chiefly of that which has been called 'Diluvial drift,' that is, of the accumulations of gravel, and other transported matter which covers up the Tertiary deposits and for the most part contains fossils, and whose origin dates back to a period not very long antecedent to the present. The Diluvium, indeed, unites, to a certain extent, the Tertiary with the recent period, but it has been found extremely difficult to account for the presence of various deposits

\* The silting up of lakes,—sometimes effected on a very grand scale,—and the formation of deltas, such as those of the Rhine, and the Ganges, are the principal operations of this kind that attract the attention of the Geologist.

of this kind, and the circumstances of their deposition have not yet been satisfactorily made out.

Before considering the nature and contents of superficial deposits, the reader should, however, be reminded that there is no actual hiatus existing between the Tertiary formations and those in progress at the present day, and that, in many parts of the continent of Europe and elsewhere, there has, to all appearance, been an unbroken continuity, so far as it is possible to judge by the organic remains that have been embedded. It is chiefly, also, in the north of Europe that the gravel is found spread over a very large surface, and it may there be traced in several directions towards the principal mountain chains.

In whatever way we consider the phenomena of gravel, and the presence of diluvial drift, frequently containing very large boulders, we can hardly avoid referring for its origin to the elevation of the loftier portions of the earth's surface; and one explanation that very naturally suggests itself to the mind is, that these subterraneous movements originated vast waves, which washed over the surface of the land, and carried along with them numerous masses of rock, loosened and broken away during the uplifting of the bed of the ocean and the adjacent land. Nor is such an hypothesis in any degree unreasonable. The tops of the most lofty mountains have in most cases risen from the bottom of the sea, and there is every reason to suppose that the series of elevations to which they have been exposed has been continued to a very recent period. Those forces, therefore, which, whether by sudden and violent efforts, or by a long series of less convulsive movements, have at successive intervals produced the great chain of the Alps, and other subordinate mountain chains in Central

Europe must, in all probability, have produced at each one of such greater upheavals, a vast wave, affecting an extensive portion of the bed of the surrounding sea or ocean, and this wave, propagated over an extensive tract of what is now Northern Europe, may have carried along with resistless violence the innumerable fragments it would wash away from the flanks of the future and rising mountains. The force of running water on such occasions has been already alluded to,\* nor can I here enlarge on the subject. I would only point out to the reader, that the adjacent low land *may* have been affected by the elevation of a considerable extent of the bed of the ocean, and I believe this elevation to be, so far as it goes, a real cause of the production of diluvial drift, and, therefore, one worth considering, although not in all cases sufficient. It is, I think, perfectly clear, that if the series of elevations which have brought the continent of Europe into its present position, and have effected its physical configuration, were the result of the often-repeated action of impulsive forces acting from beneath the earth's surface, there must have been produced through a large portion of the whole Tertiary period, and even up to the most recent time, a succession of diluvial waves, some of which may have been so extensive as to include the whole of the continent within their sweep, while others were only local, affecting particular districts, and leaving no marks of disturbance elsewhere.†

\* See *ante*, vol. i. p. 9.

† I have alluded here to the elevation of the Alpine chain, because it is the one which has, no doubt, most considerably modified the physical features of the middle of Europe. The same argument would apply to the elevation of the Scandinavian chain, and even to that of the hills of Cumberland and Wales in our own island, which have also been accompanied by similar phenomena, the result of diluvial action.

It has, indeed, been asked, whether, if the elevation of mountain chains has been accompanied by such waves producing diluvial deposits, there ought not to be Secondary or Palæozoic gravels. Doubtless, the effect at all Geological periods would be the same, but it would not necessarily exhibit itself in the same way. There is great reason to believe that during the whole of the older portion of the earth's history there was no land, with the exception of a few unimportant islands in those parts of the Northern Hemisphere now occupied by the continent and islands of Europe.

Whatever effect, therefore, of a diluvial kind may have been produced on the then existing land, or where it may have been produced, we can only conjecture, while the occasional beds of conglomerate, such more especially as the Old Red Sandstone, may possibly be a marine diluvium, exhibiting at the bottom of a sea effects analogous to those which have produced beds of gravel on land. But it should not be forgotten, also, that some of the diluvial effects now observable in Europe, may have only been completed after a long series of disturbances; and Mr. Hopkins has expressed an opinion that Geologists have frequently limited too much the period during which the transport of erratic blocks may have taken place, and he supposes that the great mass of diluvium from the Cumberland mountains might have had its origin with those ancient elevatory movements which disturbed that formation before the deposit of the New Red Sandstone.\*

But without dwelling on these points, which are, although extremely interesting, more theoretical than it accords with my plan to indulge in, let us now proceed to consider, shortly, the nature of the different phenomena

\* Proceed. of Geol. Soc. vol. iii. p. 762.

that have been described connected with the subject of diluvial drift. These phenomena are very readily classed, as the transported materials may be for the most part traced without much difficulty to some well marked, although often distant chain of elevated and mountain country. Thus, on the continent of Europe there have been drifts traced in distinct directions, one of them setting northwards from the Alps, and another southwards from the Scandinavian chain, while in England itself there are also several centres from which rocks have been transported to a distance, although by far the greater proportion of the whole are derived from the hills of Cumberland and Westmoreland.

To commence with our own country, it seems worthy of remark, that the direction of the drift or course of the transported matter conveyed from the Cumberland mountains, is chiefly to the south and east, slightly to the north, but not at all to the west;\* so that while there is scarcely any appearance of transported gravel on the borders of Scotland, the boulders have crossed the deep and broad vale of the Eden, and have afterwards crossed the Penine Hills over a pass, the height of which is 900 feet above the Eden. This Penine chain must, however, have been in existence, and have acted in some measure as a great natural dam, limiting the eastward distribution of the blocks, for the moving force was sufficient to carry the drift to the south, over all the undulated and hilly region between the mountain border of Yorkshire and Derbyshire, and the Irish Sea, the continuity being perfect at least as far as Bridgenorth, more than 130 miles from the origin of the transported matter.

This is not the only instance, however, of accumulations

\* Phillips's Treatise on Geology, vol. i. p. 270.

of drifted matter in England. The eastern counties in the middle of our island are also partly covered up with an extensive deposit of clay, including within it numerous fragments of almost all the secondary rocks.

This great mass, known as 'the Brown Clay,'\* together with many other similar, but less extensive heaps of drifted material, as yet imperfectly described and traced, offer, however, additional proof, if any were required, of the very recent action of disturbing forces, effecting considerable changes in the physical configuration of the earth's surface in our own latitudes.

But these phenomena, interesting and extensive as they are in England, are of far less magnitude than many others of a similar nature in North-Eastern Asia and America. The boulders which have travelled from the west of Cumberland over the plains of Lancashire and Cheshire are few and contemptible, when compared either with those which have proceeded across the great valley of Switzerland, from the High Alps to the Jura, or with the innumerable fragments of old rock scattered over the great plain of Central Europe and the steppes of Russia. A great part of the plain of Switzerland, for instance, is covered at intervals with fragments of rock, most of which

\* This drift is greatly extended in the counties of Middlesex, Essex, Bedford, Hertford, Huntingdon, Cambridge, Norfolk and Suffolk, and consists, chiefly, of stiff blue and yellow clay, containing masses and small fragments of rock, as well as fossils from nearly every secondary, and from many of the older formations. In some localities, clay forms the principal mass of the deposit, but in others, it contains and rests on beds of sand and gravel, and it is often overlaid by a considerable thickness (sometimes more than fifty feet) of sand gravel and chalk flint. Dr. Mitchell (Proc. Geol. Soc. vol. iii. p. 5) has expressed a decided opinion that the materials thus accumulated in the east of England, were derived from a point to the east of north. The condition and general character of the fossils in the counties of Cambridge and Huntingdon, do not altogether bear out this view, and it would seem more in accordance with the facts to speculate on a north-westerly, than a north-easterly origin. This is, however, a point of Geology not yet satisfactorily worked out.

owe their origin to the higher Alpine tracts, and an immense number of them (having each about a cubic yard of contents) strew the plain, dot the sides of the Alpine ravines, and rise on the opposite flank of the Jura range, even to an elevation of several thousand feet above the sea. The most concentrated distribution of these blocks seems to be near the town of Neuchâtel, but similar masses are also found on the summit of the Mont Salève behind Geneva. It has been well observed on this subject, that "it is difficult to convey on paper too lively an impression of the singularity of the phenomenon—a belt of fragmentary masses lying on a steep, almost precipitous slope of nearly bare or thinly-covered rock, of a nature wholly dissimilar; not few or small, but countless and gigantic."\* One of the blocks behind Neuchâtel (850 feet above the lake) is of granite, and measures between fifty and sixty feet in length, by twenty feet broad, and forty feet high,† while between the Jura and the Alps blocks still larger are in many places to be found, one out of a great number together in the canton of Berne measuring 61,000 cubic feet.

The erratic blocks and gravel which cover the plain of Central Europe and the steppes of Russia, appear to have travelled chiefly or exclusively from the north, and it is probable that a large proportion of them owe their origin to the mountains of the Scandinavian chain. Evidences of this indeed are seen in many parts of Sweden and Finland at the present day, long parallel ridges having been there observed, consisting of accumulations of rounded stones, which have clearly been separated from the rocks in the immediate neighbourhood, and the passage of these heaps

\* Professor Forbes, *Edinburgh Review*, vol. lxxv. p. 81.

† The distance from the supposed origin of this rock in a right line is seventy English miles; it is a very peculiar granite, met with in the Val Ferret, to the east of Mont Blanc.



of gravel has produced extensive furrows and deep grooves in the rocks over which they have been transported, the furrows appearing to the height of 1500 feet above the sea, but never above that altitude.

They are supposed by some Geologists who have examined them, to have existed before the formation of the ordinary European diluvium; but they must, notwithstanding, be looked upon as real diluvial phenomena.\*

In latitudes still higher than any part of Sweden, vast accumulations of sand and gravel may still be traced, and these reach even to the very shores of the Polar seas both in Europe and Asia. It is chiefly in the northern and north-eastern parts of the latter continent that they have been the objects of careful examination; but in the latitude of  $75^{\circ} 6' N.$  long.  $140^{\circ} E.$ , the hills have been found to contain the skulls and other bones of horses, buffaloes, oxen, and sheep, in such abundance that it would appear as if these animals must have formerly lived on the spot in large herds. The country, however, is now scarcely habitable, except by the reindeer; and the change that has taken place is still more strikingly apparent from the fact, that in the same district the trunks of trees of very large size have been not unfrequently found in a fossil state, at least three degrees north of any spot on which similar trees will now grow, and even where they are found living they rarely exceed the size of shrubs. In the same district in which these fossils are found, the bones and tusks of elephants are excessively abundant, and for as much as eighty years there have annually been brought away from the Lachow islands large cargoes of these bones, without any apparent diminution of the stock. M. Von Wrangel also has stated of his own knowledge, that the

\* Edinburgh New Phil. Journ. for 1837, p. 69, and 1842, p. 103.

right bank of one of the north-eastern Asiatic rivers (the Kolyma), emptying itself into the Polar Sea, in long. 160° E., consists of steep cliffs nearly 200 feet high, which are entirely made up of sands and gravel, forming a conglomerate or breccia with the bones of elephantine animals, and the whole mass being cemented together by frozen water, which the summer is too short to dissolve completely.\*

But amongst all the masses of transported matter that have hitherto been described, none seem more surprising than the myriads of great angular fragments of quartz rock covering the bottoms of the valleys in the Falkland Islands,† and called by Mr. Darwin “a stream of stones.” These blocks vary in size from the dimensions of a man’s head to ten or twenty times as large, and even more; their edges are but little water-worn, and they occur, not thrown together in irregular piles, but spread out into level sheets or great streams. In some places a continuous stream follows up the course of a valley, and even extends to the very crest of a hill; and in others the band of these fragments is at least half a mile wide.‡

But this is not the only instance on record of a great accumulation of rolled fragments in the southern hemi-

\* Von Wrangel’s Journey to the Shores of the Polar Seas, pp. 133, 185, 286.

† The Geological structure of these islands is simple, the lower country consisting of clay-slate and sandstone, and the hills of white granular quartz rock, the strata of which are arched over and bent, often in perfect symmetry. The sandstone and clay-slate are probably of the older Palæozoic period. (See *ante*, vol. i. p. 120.) Darwin, *Voyage of Adventure and Beagle*, p. 253.

‡ See Darwin’s *Voyage of the Beagle*, p. 254.

A somewhat similar phenomenon, though on a much smaller scale, has been alluded to by Mr. Lyell, in a memoir on the Geological evidence of the former existence of Glaciers in Forfarshire. (*Geol. Proc.* vol. iii. p. 342.) It mentions a continuous stream of transported materials, from three to three-and-a-half miles wide, of boulders and pebbles, traceable in a straight line, to a distance of thirty-four miles.

sphere:—Along the whole coast of Patagonia the non-fossiliferous, chalk-like bed referred to in a former chapter, (see p. 110,) is surmounted by a thick bed of gravel almost exclusively derived from the porphyritic rocks. This gravel covers the entire surface of the land for a space of 800 miles from north to south, gradually increasing in thickness as we ascend to the base of the Cordilleras. It would seem that to account for the covering of this vast tract with what must be called Diluvium, we need only assume a gradual and successive elevation of the great chain of the Andes, and that it is not necessary to call in the aid of any more violent disturbances to effect this than the upheavals still occasionally experienced on the coast of Chili.\*

The gravel just described is covered at Port St. Julian and elsewhere by a very irregular and thin bed of reddish loam, which was found by Mr. Darwin to fill up in one spot a hollow or gully, worn quite through the gravel, and in this mass a group of large bones was found embedded. Much farther to the north, and in the extensive plains south of the Plata, the gravel itself was found to contain the remains of large animals, which seem to abound in the cliffs along that part of the South American coast.†

\* The subject of the erratic blocks of South America is one of far too great extent to admit of anything more than a mere allusion in this place. A memoir read before the Geological Society by Mr. Darwin, and afterwards printed in the Transactions, (2nd Ser. vol. vi. p. 5, *et seq.*) is full of important detail on the subject, and gives a connected view of many different phenomena of the same kind, which are also of the same Geological epoch. The Cordilleras would appear to be, almost throughout, the parent rock; and along the whole line of coast and the country extending from the great chain of the Andes to the sea, there is little variety, and all the phenomena are on the grandest possible scale.

In Mexico, again, sand and gravel form extensive metalliferous deposits, and in other northern parts of South America similar phenomena have been recorded.

† These remarkable animals, the former of which has been named by Mr. Owen, *Macrauchenia*, while the latter include the extinct genera of *Toxodon*, *Myiodon*, *Glyptodon*, *Megatherium*, and several others, will be described in the ensuing chapter.

Many parts of Africa appear to exhibit proofs of such disturbing forces having acted in comparatively modern times, as to cause the deposition of extensive beds of gravel and drift. In the north-east of that great continent, of which so little is known geologically as well as geographically, the valleys of Upper Egypt are covered with the detritus of neighbouring rocks, and with rolled pebbles transported from a distance, which often rest on ledges and hills much above the general drainage level.\* It is probable that similar phenomena might be traced along the whole northern coast of Africa, while the sands of the desert, which succeed and often approach so nearly to the coast, must ever prevent the acquirement of any certain knowledge of the structure of the interior. At the southern extremity of Africa, the soil is derived chiefly from decomposed granite, and this, at the Cape of Good Hope, is sometimes accumulated to the thickness of a hundred feet, and is everywhere covered with enormous blocks of sandstone, and occasionally of granite.†

North America exhibits numerous appearances of superficial deposits which scarcely yield in magnitude, or in the interest attaching to their contents, to those of the more southern part of the western continent. Almost the whole surface of North America, as far as it has been examined, has been found covered with gravel, pebbles, and boulders, varying greatly in thickness, and obviously of the same origin as the similar deposits in Europe; and a region which has been called the great Atlantic plain,‡ extending between the Alleghany mountains and the Atlantic ocean, together with the lower part of the great valley of the Mississippi, appear to be the districts where

\* Geol. Proc. vol. iii. p. 783.

† Loc. cit. p. 421.

‡ Report of the Fourth Meeting of the British Association, p. 3, *et seq.*

it conceals the under-lying deposits to the greatest depth. On the eastern part of this extensive territory the deposit consists chiefly of fine sand and gravel, but the pebbles even there belong almost entirely to the older rocks of the interior. As we advance towards the interior from the coast, the mass of diluvial matter becomes less sandy and coarser, and at length, near the rocky boundary of the plain, the gravel is much coarser, rolled blocks and large boulders occurring, but alternating with clayey beds sufficiently pure to be used in the manufacture of bricks.

The distribution of the Diluvium in this part of North America is stated by Professor Rogers\* to be invariably from the north-west and north, and it is seen west of the Alleghanies, throughout the region of the Ohio and the Mississippi, and also in latitudes north of the United States.

The extent and magnitude of the moving force required to produce these gravels of America must certainly have been extremely great, for in some places detached blocks brought from a great distance, and weighing several hundred pounds, rest on the ordinary finer Diluvium, and are promiscuously dispersed over a great extent of country in Ohio, Kentucky, and Indiana, although in the more southern state of Alabama not a boulder appears on the surface.

On the borders of the lakes Erie and Ontario there are very decided marks of the great drift which has elsewhere overspread North America, and the boulder formation containing marine shells extends into the valley of the St. Lawrence, as far down as Quebec, and at a height of at least 300 feet above the sea-level. Below Quebec there are large and far-transported boulders in beds, both above and below these marine shells, and wherever

\* Loc. cit. p. 16.

the contact of the drift with hard subjacent rocks is seen, these rocks are smoothed and furrowed on the surface, as they are in similar positions in Northern Europe. The character of the fossils also indicates a more arctic climate than that which now obtains in the neighbourhood.\*

It is not a little difficult to determine the actual limit of such formations as are to be considered merely diluvial and superficial in a country like North America, where existing causes have acted so energetically. The gigantic rivers which traverse that continent produce in a short time modifications, which are only equalled in amount by the long-continued action of the less effective streams of Europe, and it is not easy for those accustomed only to consider the less violent and extreme changes to appreciate fully the amount of alteration that may take place by existing and ordinary causes of such magnitude.

In many parts of North America valleys are filled up to the depth of twenty or thirty feet with unconsolidated beds of earth of various kinds, and the heterogeneous mass contains in it abundant remains of large pachydermatous animals, not now living in the country, but associated with, and overlaid by other and similar beds, in which occur the bones of buffaloes, that have within a few years been driven westward by the advancing steps of civilized man. These beds, however, must be considered to be of *alluvial* origin, employing here the word alluvium to express such deposits as are left by the running streams, or the lakes, that now exist, or that have till very lately existed in the country. They all belong to the same Geological period, or nearly so, and a description of one will be sufficient to give an accurate notion of a multitude of similar bogs and soft

\* Mr. Lyell, Geol. Proc. vol. iv. p. 20.

meadows in many of the western States. The most remarkable is that known as 'the Big Bone Lick' in Kentucky.

The Big Bone Lick occupies the bottom of a boggy valley, kept wet by a number of salt springs, which rise over a surface of several acres, and the substratum of the country is a fossiliferous limestone. At the Lick the valley is filled up to the depth of not less than thirty feet with beds of earth, the uppermost of which is a yellow clay, apparently the soil brought down from the high grounds by rains and land floods. In this yellow earth, along the water-courses at various depths, the bones of buffaloes and other modern animals are often found quite entire. Beneath the clay is another layer of a different soil, bearing the appearance of having been formerly the bottom of a marsh. It is more gravelly, darker-coloured, and softer than the other, and in it, or sometimes in a stratum of compact blue clay alternating with it, there are found innumerable bones of large mammals, chiefly mastodon, but including also elephants and extinct species of animals of the ox and deer tribe.\*

It would not be right to quit the subject of diluvium without at least alluding to the singular appearance often presented on the surface of rocks over which diluvial matter has passed, an appearance which has given rise to

\* In other localities the mastodon bones are found immediately below the surface in reclaimed marshes, and they are sometimes extremely perfect, sometimes broken and water-worn. The Big Bone Lick would appear to have been resorted to, not only in modern times by the living races, but more anciently by animals now extinct, for the salt and perhaps the food produced by the marsh. The buffalo and bison are frequently known to perish entrapped in these licks and swamps, and it seems evident that the mastodon and elephant of former times must, from their huge size and unwieldy forms, have been at least equally exposed to the same fate.— See Prof. Rogers' Paper in the Report of the Fourth meeting of the British Association, pp. 23. 28.

very great discussion within the last few years, as connected with the theory of glacial action, and the share that may have been taken by ancient glaciers in the transport of gravel and blocks of stone in various parts of the world.

Professor Playfair seems to have been the first to suggest that glaciers—those masses of ice which proceed from lofty and snow-clad mountains, filling up ravines, and often stretching down into the plain country—were also most powerful agents employed by nature in the transport of huge blocks of stone and heaps of detritus. Since however it has been distinctly proved, first, that glaciers are usually loaded with parallel heaps of stones, often of large size, and extending along their whole length, called *moraines*; and next, that they move steadily onwards, conveying these rocky heaps and depositing them at the side or termination of the glacier, it is sufficiently evident that they may have conveyed great quantities of gravel and erratic blocks in those mountain districts where they have at any time prevailed.\*

One of the effects produced by the motion of a glacier, loaded with debris and moving slowly over the exposed face of a rock, has been shewn to be a rubbing, wearing, and polishing of the surface which is passed over. The effect thus produced may indeed be considered as three-fold, consisting of, first, a rounding of the angles of

\* With regard to the cause of the motion of glaciers, it is a subject on which I shall not at all discuss in this place. There is no question whatever as to the fact that a slow but steady advance does take place, the glacier not extending farther into a valley under ordinary circumstances, because it has already reached the point at which the waste by melting is equal to the amount by which the whole mass is pushed forward. A difference in the temperature of the summer for two or three years in succession, does, however, effect a manifest change in the glacier, the abrupt termination of which in the valley advances or recedes under such circumstances according as the average temperature is diminished or increased.



the rocks passed over ; producing in the next place deep undulating grooves upon them, more or less nearly parallel to one another, and longitudinal ; and thirdly, scratching with fine striæ the polished surface of the rock passed over, even when it is of the hardest quartz. These three effects, which are well known to be produced by the passage of modern glaciers, have also been observed, as I have already stated, to a greater or less extent in many parts of the world, far removed at present from glacial action, and they have been considered by M. Agassiz and other Geologists as affording sufficient proof that the occurrence of gravel and erratic blocks is a phenomenon only to be explained by supposing that glaciers must formerly have occupied the tracts thus covered. Whether such a theory can be safely applied in every instance, is, perhaps, more than doubtful ; but it is certainly entitled to rank among '*geological probabilities*,' and although presenting numerous difficulties, these are perhaps fewer and less unmanageable than those which surround the other attempts that have been made to explain the same phenomena.

Instances of rocks polished, grooved, or striated, have now been met with abundantly in Scotland, as well as on the flanks of the Jura, and Dr. Buckland has discovered what he considers to be indications of glacial action in the Cumberland and Westmoreland mountains, as well as near Edinburgh and in the Grampian chain. They have been found also on other continents, and Dr. Hitchcock gives the following account of certain appearances observable over a large tract of country in North America : " These striæ and grooves," he says, " generally point south-easterly over a breadth of 2000 miles of country ; they appear on mountains to a height of 3000 feet, but not on those which exceed 4000 feet above the level of the

sea, and they are more feeble and fainter in the south of the United States than in the north.”\* These phenomena, therefore, if they are referrible to glacial action, are exhibited on a scale commensurate with the magnitude of the American continent.

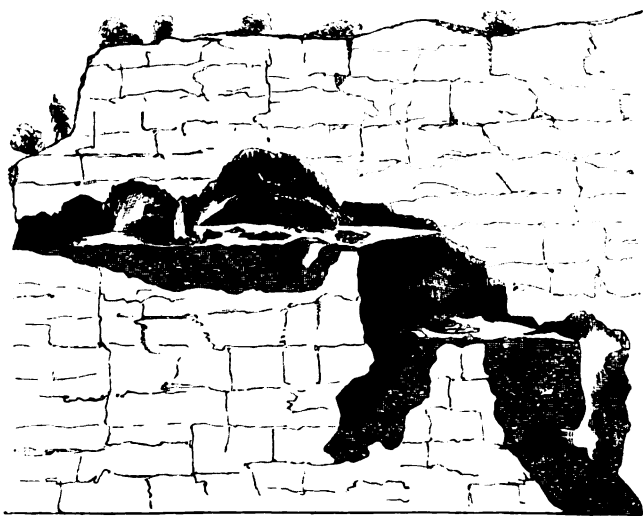
The diluvial deposits of Asia, south of the great chain of the Himalayas, present several very remarkable diluvial phenomena, though without much reference to the subject of glacial action. The material which most commonly forms the superficial covering of the older rocks consists of the irregular clayey bed called *kunkur*, which has been already alluded to, and which is expanded over extensive plains, and even caps some of the secondary hills in the interior of the peninsula of India. Numerous varieties of this ‘kunkur’ are described, and they all seem to differ considerably from contemporaneous European deposits, perhaps rather resembling the Brown clay of Cambridge-shire and the Fens, than any other of the European diluvial heaps. Organic contents are rarely found in it, and the absence of these, together with the almost invariable presence of oxide of iron and carbonate of magnesia, is a very curious mineralogical phenomenon.

Besides the *kunkur*, there is also a considerable development of regular diluvial drift in various parts of Hindostan, and probably throughout the continent of Asia. In Cutch, the Tertiary Geology of which has been already described, there exist great plains, almost entirely made up of loose gravel, which also abounds on the coast near Bombay, and in the Deccan immense quantities of loose basaltic stones are strewed upon the land, and are sometimes heaped together in rocky masses, forming hills from twenty to seventy feet in diameter, and the same in height.

\* Jameson’s Phil. Journ., 1842, p. 76.

Farther to the east, and in the direction of the great chain of the Himalayans, the gravel and boulders are more abundant, and afford more distinct proof of their origin. In a low range to the north of Delhi, Capt. Cautley\* speaks of enormous strata of diluvial gravel, containing boulders of granite, gneiss, mica slate, &c. which are cemented into a solid conglomerate, and rise upon the hill at an angle of from twenty to thirty-five degrees. In Bundelkund, also still further to the south, the gravel and boulders are represented as being very extensive.†

## OSSIFEROUS CAVERNS.



VIEW OF THE INTERIOR OF THE CAVE OF GAILLENREUTH.

I have selected the present chapter as the most proper place to consider the subject of caverns common in lime-

\* Asiatic Researches, vol. xvi. p. 392.

† Ibid., vol. xiii. p. 23. Near Bombay, agates and onyx stones are collected from diluvial beds of gravel.

stone rocks, and of which there are many interesting specimens in almost all parts of the world ; for although the period of silting up the caverns is often a matter of some doubt, their fossil contents unquestionably consist of the remains of animals which immediately preceded man upon the earth.

The origin of these caverns, which are usually found in hilly or mountain districts and which often extend more in a vertical than a horizontal direction, must probably be referred in most cases to mechanical violence, affecting the rocks long since their deposition.

Those caverns which are found to contain fossil bones in any abundance are commonly cracks and fissures connected with faults in limestone rocks—the height of the ossiferous floor above the level of the sea is rarely so much as three thousand feet, and the floor consists of a marly clay or silt mixed with gravel and angular blocks of stone, and containing bones irregularly distributed amongst the silt and gravel.

Two of the most extensive and celebrated bone caverns in England are those of Kirkdale, in Yorkshire, and Kent's Hole, near Torquay, but these are surpassed in magnitude, and in the abundance of their fossil contents, by other similar ones in the north of Bavaria, in a district well known to tourists as the Franconian Switzerland.\*

\* The cave of Gailenreuth, of which a sectional view is given in the diagram, is one of the most remarkable of those in Northern Bavaria for the quantity and the high state of preservation of the bones that have been extracted from it. It consists principally of two large chambers, varying in breadth from ten to thirty feet, and in height from three to twenty feet. The floor in each chamber was nearly covered by stalagmitic incrustations when the cavern was first opened, but has since been nearly destroyed by holes dug through it in search of the prodigious quantities of bones that lie beneath. Beyond the second cave, and connected with it by a low and narrow passage, there is a smaller cavern, at the bottom of which is a nearly circular hole from three to four feet in diameter, and descending about twenty-five feet, and in descending this hole its circumference is found to be

Many other instances of fossiliferous caverns occur in the Hartz and elsewhere in Northern Germany; in many parts of France; in Belgium, chiefly in the valley of the Meuse and the small tributary valleys to that river; and in Styria and Hungary. It is remarkable that while the bones of the *Hyæna* form by much the largest proportion of those obtained from the English caverns, the remains of a large and extinct species of Bear, although found in England, are much more common on the Continent.

The history of these caverns appears to have been in most cases nearly the same. A crack or crevice in a limestone rock exposed at the surface has, by the passage of water, been gradually enlarged, and an outlet has at length been made on a hill-side sufficiently large to admit some of the larger carnivora. Successive generations seem to have lived and died in the recesses of these dens, and occasionally the prey of the hyænas or bears who inhabited them has been dragged in to be devoured at leisure, the gnawed bones being left on the ground, or heaped among loose fragments of stone. After a time the circumstances of the country have altered; the caverns have been silted up by the intrusion of water holding mud in solution, and a constant incrustation of lime going on in the form of stalagmite has accumulated on the floor of the cavern and preserved these remains, until by some accident their existence has been discovered at a long subsequent period. In many cases the relative level of the land has changed, but in others it is probable that the period during

for the most part composed of a breccia of bones, pebbles, and loam, cemented by stalagmite, but how far this may extend is not at present known. The state of preservation of the bones is quite perfect when they are encrusted with stalagmite, and the colour is then yellowish white. In other cases, where they are extracted from loose earth, they are of a brown or blackish colour.—Buckland's *Reliquiæ Diluvianæ*, p. 133.

which these carnivora lived in Europe was succeeded by a gradual obliteration of the evidence of their previous existence.\*

Before concluding this chapter, I ought to allude, though it can only be very shortly, to the recent formations of sandstone and limestone now going on in different parts of the world, as in the islands of the West Indian Archipelago, in Ascension Island, and in many places on the coast of South America.

The island of Guadeloupe has long been celebrated for containing, embedded in a limestone now rapidly forming on the coast, the fossil remains of human beings. This rock is composed of sand containing a large proportion of comminuted shells and corals formed into a stone by means of a calcareous cement, and it contains the remains of many recent land shells together with fragments of pottery, and ornaments of stone and wood. A similar deposit, forming on the shore of Ascension Island, includes the eggs of turtles with other remains of recent species of animals, and the sand on the shore of the island of Madeira has also agglutinated into a hard rock, enclosing recent shells and fragments of wood.† Mr. Darwin

\* The remains of as many as 300 hyænas have been obtained from the cavern at Kirkdale, which also yielded the bones of several ruminants, bearing every mark of having been gnawed by the teeth of the hyænas. They were found mixed confusedly with loam or mud, and also dispersed through the crust of stalactite, which covers this ancient floor. Caverns in Australia have recently been described by Sir T. Mitchell, containing fossil bones of a large extinct kangaroo, cemented into a breccia by red ochreous matter. A similar breccia, cemented by carbonate of lime, is common in the rocks at Gibraltar, which are also much pierced with caverns. In Brazil some very remarkable natural excavations have lately been discovered, containing innumerable remains of quadrupeds, for the most part extinct, and of those species which are also found in the Pampas Clay.

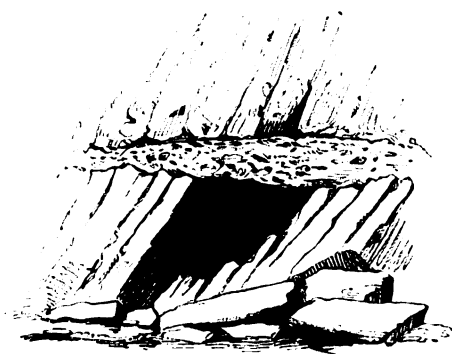
† It appears probable from recent observations that this agglutinated sand of Madeira belongs to a period somewhat more ancient than the Guadeloupe limestone.

mentions a somewhat analogous deposit on the coast of Patagonia, in which fragments of pottery are embedded with marine shells, at a height of a hundred feet above the sea level, indicating apparently an elevation of the coast line to that extent within a very recent period.\*

The phenomena of raised beaches in our own island has been already alluded to, and is well illustrated in many parts of the south-western coast. The subjoined vignette exhibits a locality in which the raised beach has become so consolidated, that the sea has worn out a cave upon the top of a small fault under the beach, that supports a head of angular fragments derived from the hill above, where the continuation of the grauwacke beds appear. Large fragments of the consolidated raised beach occur scattered in the present beach and accompanying the fragments of grauwacke.†

\* Voyage of the Beagle, p. 452.

† De la Beche's Report, p. 431.



## CHAPTER XLIV.

THE FOSSIL REMAINS OF QUADRUPEDS AND BIRDS FOUND IN CAVERNS AND EMBEDDED IN GRAVEL, OR OTHER SUPERFICIAL DEPOSITS.

THE superficial deposits of diluvial and alluvial drift in almost every country abound with organic remains, a large proportion of which are usually found to be referrible to species not now inhabiting the same district, and many of them totally extinct. The present chapter I propose to devote to the consideration of some of these, confining my remarks, however, to those which exhibit important and interesting peculiarities of structure, or which are remarkable for the circumstances under which they have been found.

The Quadrupeds whose remains are found fossil in the gravel and other superficial deposits of Europe, belong to those orders of Mammalia still common in this part of the world, and it will be convenient to describe them in groups, as they are characteristic of particular geological localities. Thus the Carnivora being most frequently found in caverns and ossiferous breccia, form one of such groups, and the bones of Ruminants abounding in the gravel of our own country, and found embedded in fens and alluvial deposits, another; while the remains of Pachyderms, also found in gravel associated with those of



Ruminants in our own country and throughout Europe, are most abundant in the remarkable fossiliferous gravels of the Polar Seas, and are extremely characteristic of the singular heaps of detritus in many parts of North America. South America is remarkable for containing in the superficial drift which covers a large part of that continent, the remains, sometimes perfectly preserved, of many new and very interesting species of *Edentata*. This tribe of animals, which is, indeed, the one which still predominates in that part of the world, formerly, and at no very distant period, occupied a far more important place in the animal kingdom, containing species (whose remains are there found) rivalling in size the largest of the terrestrial mammalia, and presenting anomalies of structure exceedingly curious and interesting. Lastly, from New Holland, where species of such animals are still existing, we obtain also a few extinct Marsupial species of gigantic proportions, and from New Zealand a group of wingless birds, whose nearest analogues are still found in the same island. The bones of Rodents and Cetacean animals are sparingly distributed over a wide space, while the *Quadrumanæ*, if met with at all in gravel, only occur in Asia, where such animals are at this day most commonly found. As the gravel fossils of these three latter orders exhibit but few and unimportant peculiarities of organisation compared with the others, I shall not again allude to them in this chapter.

The order *CARNIVORA*, which includes the most fierce and mischievous quadrupeds, has naturally been the one most completely subdued, and that which has suffered most diminution by the advancing civilization of man in every part of the world; and thus it happens that at the present day the Fox, the Wild Cat, and the Badger,

remain the only representatives of the three families of this important group still indigenous in Great Britain.\*

But even the annals of history point to a time when the case was far different, and we know that the Bear, the Wolf, and the Hyæna have ranged at liberty in the extensive forests which covered the greater part of our island, at a period which, geologically speaking, is recent, and which even so far as man is concerned, can only be considered as of moderate antiquity. The remains of these animals are abundantly distributed in the gravel, in turf bogs, in the fens, and in caverns in limestone rocks.

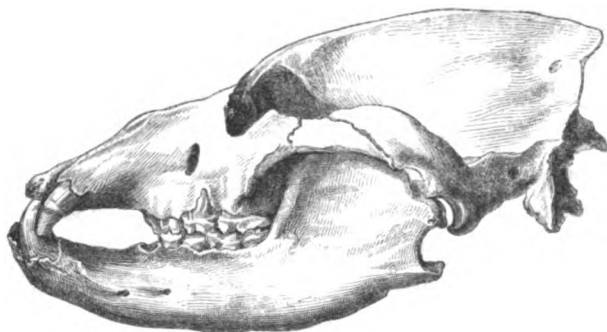
Several extinct species, both of Bear and Hyæna, have been determined, most of them being obtained from the mud and silt at the bottom of natural caverns in limestone rocks, but it is a fact, which I have already alluded to, that by far the most abundant remains of Carnivora in England are those of Hyænas, while on the continent those of the Bear are predominant. Both, however, are found in tolerable abundance, and these animals, which attained dimensions at least one-third larger than any recent species, must have been incredibly abundant during a long period. They seem to have inhabited the caverns for a series of successive generations, and in many cases the prey they obtained was dragged to their abodes, where the gnawed bones are still found.

The bear of the caverns (*Ursus spelæus*) appears to have resembled most nearly the huge grisly bear of North America, but was a larger and apparently a much more powerful species.† From the proportions of the molar teeth,

\* Owen's British Fossil Mammalia, p. 77.

† M. de Blainville has indeed expressed a doubt of the existence of any such differences as can satisfactorily distinguish between the cavern bear and the recent species inhabiting the western part of North America (*U. arctos* var. *ferax*). But it would seem, that these doubts are not well founded, as the differences

however, and from some peculiarities of appearance and wearing, it has been inferred that this extinct species fed more on vegetables than its recent analogue, and that



SKULL OF *URSUS SPELÆUS*.

(One sixth of the natural size.)

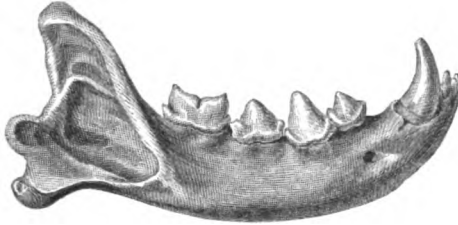
the vegetable food, in whatever proportion it entered into the diet, was of a soft nature, consisting of berries, or tender twigs and sprouts. "The size and strength of the *Ursus spelæus*, and the huge canines with which its jaws were armed, would, however, enable it to cope with the large Ruminants and ordinary Pachyderms, its contemporaries in ancient Britain and on the Continent, and to defend itself successfully against the large Lion or Tiger, whose remains have been found in the same caverns."\*

The caverns of England, although not without fragments of the great extinct species of Bear just described, contain in far greater abundance the bones and teeth of the more carnivorous *Hyæna*, which, both in its dentition and its habits, approaches more nearly than the Bear to the feline tribe, although, as it rather seeks the dead carcase than a

are stated by Professor Owen to extend to important and characteristic points of structure.—Owen's British Fossil Mammalia, p. 88, *et seq.*

\* Owen's Brit. Fossil Mammalia, p. 101.

living prey, it is far less destructive than the Lion, the Tiger, or the Leopard.



RIGHT LOWER JAW OF A HYÆNA.

*(One fourth of the natural size.)*

The molars or grinding teeth of the Hyæna are admirably adapted for gnawing and breaking bones, and are readily distinguishable by their shape, by the strong conical ridges characterising the pre-molars, and by the belt of enamel at the base of this cone to defend the gum. The existing species of Hyæna are confined to warmer climates than our own, one of them inhabiting Northern Africa and the adjacent parts of Asia, and two others being only found near the Cape of Good Hope. The extinct species found in England, and in the drift and gravel in various parts of the continent of Europe, more resembled the spotted Hyæna of the Cape than the striped Hyæna of Abyssinia, but was a much larger and more formidable animal than either of these species. The abundance of this animal, and the length of the period during which it was an inhabitant of England, may be in some measure understood by the following extract from Dr. Buckland's account of the opening of one of the Hyæna caverns—the celebrated one of Kirkdale, in the vale of Pickering in Yorkshire.\*

\* This cavern extends about 250 feet into the interior of the hill, from the side of which it opens and expands, and contracts irregularly varying from two to seven

“The bottom of the cave on first removing the mud was found to be strewed all over like a dog-kennel from one end to the other with hundreds of teeth and bones, and on some of the bones marks could be traced, which on applying one to the other, appeared exactly to fit the form of the canine teeth of the *Hyæna* that occurred in the cave. Mr. Gibson alone collected more than three hundred canine teeth of the *Hyæna*, which must have belonged to at least seventy-five individuals, and adding to these the similar teeth I have seen in other collections, I cannot calculate the total number of *Hyænas* of which there is evidence at less than two or three hundred.”

The remains of several other carnivorous animals have been found associated with these Bear and *Hyæna* bones, both in the caverns and the gravel. Dr. Buckland mentions two canine teeth and a few grinders, exceeding in size those of the largest Lion or Bengal Tiger, and of a species nearly allied to the latter. In a cavern near Plymouth several bones and teeth, not distinguishable from those of the recent Wolf, were found, and one of them exhibits a singular example of diseased bone, probably the consequence of an injury inflicted by the bite of a stronger animal. It would appear that the Wolves which remained in England till long after man had taken

feet in breadth, and from two to fourteen feet in height. The floor of the cave, composed of the limestone of the district, has its irregularities (which are apparently not great) filled up throughout to a nearly level surface, by the introduction of a bed of mud. In the whole extent of the cave very few large bones have been discovered that are tolerably perfect, most of them being broken into small angular fragments and chips, but in some few places where the mud was shallow, and the heaps of teeth and bones considerable, parts of the latter were elevated some inches above the surface of the mud and its stalagmitic crust, and the upper ends of the bones projecting, have become thinly coated with stalagmitic incrustations.—*Reliquiæ Diluvianæ*, p. 15.

up his abode in the island, and in Ireland till a century and a half ago, were the lineal descendants of those which, at a much more remote period, left their bones in the limestone caverns by the side of the extinct Bears and Hyænas.

The Badger, the Pole-cat, the Weasel, and the Otter, animals which are not yet completely extirpated, are also found fossil, both in the fen lands of Cambridge-shire, and also in the caverns associated with the larger Carnivora which are now extinct.

The Badger, indeed, would seem to date back to a much more ancient period than any other existing species of Mammal, for a specimen exists in the museum of the Philosophical Institution at York, which is said to have been obtained from the Red Crag of Suffolk, and which seems to possess the mineralised condition and general appearance which characterise the ordinary fossils of that middle Tertiary formation.

“A portion of the lower jaw of an Otter from the Norwich Crag at Southwold, and the characteristically bent humerus from the same formation near Aldborough, which Mr. Lyell has proved to be partly of fluviatile origin, carry the date of the common Otter in England as far back as the older Pliocene period.”\*

Besides the remains of Carnivora, fragments of In-

\* Owen's British Fossil Mammalia, p. 120.

In giving these proofs of the ancient existence of mammalian remains of species of animals still living in our island, I have almost confined myself to quoting the language of Professor Owen on the subject. Every additional fact bearing on the subject must be extremely interesting, and by accumulating such facts, and bringing them to bear upon the question, we may perhaps hope in time to overcome some of the difficulties that have hitherto prevented Geologists from determining the conditions of temperature in European latitudes, during the Upper Tertiary and immediately before the recent period. It would be, to say the least, extremely unlikely that any intervals of great refrigeration should have intervened, if the same species of animals inhabited the land during the whole period.

sectivorous mammals, such as the Mole, the Hedgehog, and the Shrew, have been from time to time discovered, both in the gravel and in caverns, but they are, for the most part, if not entirely, referrible to species which exist at the present day in the country, and even in the districts in which these fossils occur.

The bones of various ruminating animals, many of them nearly allied to the common species of *Bos* and *Cervus* (the Ox and the Deer tribes), are exceedingly abundant in the gravel of many parts of England, and also on the Continent. They seem to prove that great herds of wild cattle and deer overspread the country before it was inhabited by man, and amongst the fossils of this kind that have been found, some new species, and even sub-genera have been determined. Perhaps the most remarkable of these is an extremely gigantic animal of the Deer tribe found in the east of Ireland and in the Isle of Man, and often called the 'Irish Elk':—a species



HEAD OF MEGACEROS HIBERNICUS.

(*Enniscorthy.*)

remarkable for the extreme dimensions of its horns, and which must have been the largest and the most magnificent of all the noble animals of its tribe. It has been

placed by Professor Owen as the representative of a new sub-genus, to which the name *Megaceros* is given from the most striking of its peculiarities of structure. Perfect specimens of the skeleton have been not unfrequently dug up from the peat-bogs on the south-east coast of Ireland, and detached bones are exceedingly common there and in similar localities elsewhere. The specimen of which the head is figured in the preceding page, measures five feet six inches in height, nearly eleven feet from the snout to the tip of the tail, and the width between the tips of the horns is nearly nine feet. Almost every bone is perfect.\*

It is worthy of remark that the indigenous species of Ruminantia at the time when our island was peopled by the large extinct Carnivora, differ far less to all appearance from those still remaining, than do the Bears and Hyænas from the living species of these animals. The large dimensions of their bones, indeed, indicate that they attained enormous size, but the specific differences were exceedingly slight.

In the superficial deposits of diluvial drift there have been found throughout Europe and in Northern Asia, as well as in North America, innumerable bones of the larger Pachyderms, and these appear to become more and more abundant as we approach the ice-bound regions within the Arctic circle. In the gravel of our own island the bones and teeth of Elephants, together with those of Rhinoceros, are everywhere found associated with similar fragments of the larger Ruminants. The species both of Elephant and Rhinoceros, differ from those still living; but so far as regards the former the differences

\* This specimen is in the Woodwardian Museum of Geology in the University of Cambridge.



are inconsiderable, and could not have corresponded to any important peculiarities in the habits of the animal. The singularly elongated form of the head of the more common species of fossil Rhinoceros, and the shape of the cranium, distinguish it entirely and readily from either of the existing species.

By far the most remarkable and interesting fossil among those which exhibit but slight departures from known species, was the entire carcase of an extinct species of Elephant, discovered about the commencement of the present century, on the shores of the Polar Seas. This discovery has been already alluded to (vol. i. p. 72), but it is worth while here to describe, in some little detail, the circumstances under which the animal was found after being entombed during a long succession of ages.

The first appearance of this singular fossil was observed in the year 1799, by a fisherman who was in the habit of seeking along the shores of the Frozen Sea for the tusks of the mammoth (the name given to the Siberian Elephant), and who then noticed a shapeless mass projecting from some blocks of ice, but was unable at the time to discover what it was. During the next summer (1800) this object was more disengaged from the ice, but it was not till 1801 that any part was actually exposed; and at the end of that summer the entire side of the animal, and one of its tusks, was quite free from ice. The summer of 1802 was cold, but in 1803, part of the ice between the earth and the mammoth having melted more rapidly than the rest, the enormous mass ceased to be sufficiently supported, and fell by its own weight on a bank of sand. In March 1804, the discoverer visited his mammoth and cut off the tusks, which he sold, and two years afterwards, being the seventh year from its

discovery, Mr. Adams, then in the employ of the Emperor of Russia, happened to be traversing these regions, and, hearing of a circumstance so extraordinary, visited the spot, and found the carcase in the same place, but altogether mutilated. He found also that there was no obstacle in the way of his removing all that remained, the proprietor being contented with his profit for the tusks, and the flesh having been cut off by the people in the neighbourhood and used to feed their dogs during a time of scarcity. Wild beasts, such as white bears, wolves, and foxes, had also fed upon it, and the traces of their footsteps were seen around. Mr. Adams observes, "The skeleton, almost entirely cleared of its flesh, remained whole, with the exception of one fore leg. The head was covered with a dry skin; one of the ears, well preserved, was furnished with a tuft of hairs, and although these parts have necessarily been injured in transporting them to St. Petersburg (a distance of more than seven thousand miles), yet even the eyes have been preserved, (the pupil of one is said to be still discernible,) and the brain remained in the skull, but was dried up.

"The mammoth was a male, with a long mane on the neck, but is without tail or proboscis, although the marks of the insertion of the proboscis are visible on the skull. The skin, of which three-fourths remains, is of a dark grey colour, covered with a reddish wool and blackish hair. When first brought the skin was offensive, but it is now quite dry and hard, and, where most compact, is about half an inch thick. The dampness of the spot where the specimen had lain so long, had in some degree destroyed the hair, but that which remains on the skin is of the colour of camel's hair, and is an inch and a

half long, very thick set, and curled in locks. It is interspersed with a few bristles, about three inches long, and of a dark reddish colour."

The entire carcase, measured on the spot, was found by Mr. Adams to be nine feet four inches high, and sixteen feet four inches long, without including the tusks, which measured nine feet six inches along the curve, but the curve was considerable, the distance from the base to the point being only three feet seven inches. The two tusks together weighed 360 pounds avoirdupoise, and the head, with the tusks, weighed 414 pounds. The skin was not weighed, but was so heavy that ten persons found great difficulty in transporting it to the shore. After collecting the bones and removing the skin, the ground around the spot was carefully dug to ascertain if any of the bones remained buried and in order to collect the hairs which the white bears had trodden into the ground while devouring the flesh, and in this way more than thirty-six pounds of hair were collected.

The skeleton is now in the Museum of the Academy of St. Petersburg, having been purchased by the Emperor of Russia for the sum of 8,000 roubles (upwards of a thousand pounds sterling).

In addition to the *Mammoth*, or Siberian Elephant, the remains of two other extinct animals are stated to have been found along the shores of the Arctic Ocean. The head of one of these bears some resemblance to that of the Rhinoceros, but appears to differ from any known species. It measures upwards of thirty inches in length, and is about a foot broad, and the nose is said to be bent downwards, and to exhibit several rows of bony excrescences. We are also told, that in an island in latitude 75° and long. 140°, in the Polar Sea, the hills in the

interior were found to contain the skulls and bones of horses, buffaloes, oxen, and sheep, in such abundance that these animals must formerly have lived there in large herds.\*

Associated with the remains of large Pachyderms still inhabiting Asia and Africa there are occasionally, but rarely, found both in England and on the continent of Europe, some fragments that have been referred to a nearly allied genus, called *Mastodon*. The Mastodon, seldom met with in Europe, is however not uncommon among the fossils of Asia, and is still more abundant in North America, where it would seem to have been the ancient representative of the Elephant. In its general appearance, indeed, it could not have differed greatly from that gigantic quadruped, while it rivalled it in vastness of proportions. Its body would seem to have been longer, its limbs thicker and shorter, and, perhaps, its form, on the whole, rather approaching that of the hippopotamus, which it probably resembled also in some of its habits. Its mouth was broader than that of the elephant, and although it was certainly provided with a long trunk, it must have lived on soft succulent food, and it seems to have rarely left the marshes and muddy ponds in which it would find the most abundant sustenance.†

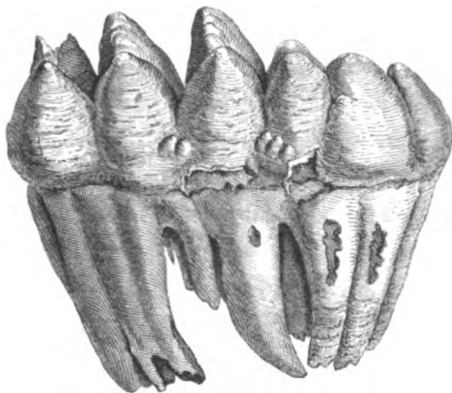
The most characteristic difference between the Mastodon

\* Von Wrangel's Journey to the Polar Sea. Introduction, p. 133.

“The best bones, as well as the greatest number, are found at a certain depth below the surface, usually in clay-hills, more rarely in black earth. The more solid the clay, the better are the bones preserved, and experience has shewn that more are found in elevations situated near higher hills, than along the low coast or on the flat tundra (moss-levels).”—Ibid. p. 286.

† A large and nearly complete skeleton of a male Mastodon was brought to this country, some few years ago, from North America, and has been purchased by the Trustees of the British Museum. It is now articulated, and is perhaps one of the most interesting specimens in the collection of Fossil Mammalia at present in the Museum.

and Elephant, consists in the peculiar structure of the grinding teeth; the enamel, which in the teeth of the elephant is deposited in plates or layers alternating with softer bone, entirely coats the surface of the teeth in the Mastodon, as in the Tapir, and in this respect exhibits analogies with the pig, and the greatest departure from the Ruminant type.\*



TOOTH OF MASTODON.

The remains of *Pachydermata* found fossil in the gravel of South America, and in the superficial deposits distributed over the great plains of the Pampas are few, but possessed of considerable interest in the analogies they offer with other quadrupeds. Amongst them a genus that has been named by Professor Owen *Toxodon*, is especially remarkable in its approximation to the various

\* Some of the Mastodons of Asia (of which several fine and highly interesting fragments are now in the British Museum, in the collection presented by Capt. Cautley), are considered by Dr. Falconer as tending to break down the distinction between this genus and elephant. They certainly exhibit a passage of a very singular kind in the arrangement of the enamel in the grinding teeth, and also approximate the two genera in another important distinction that has been observed in the proportions of the hinder part of the skull.

natural orders of RODENTIA, RUMINANTIA, and CETACEA, and it was originally described as a Rodent, in spite of its gigantic proportions, the skull measuring twenty-eight inches in length, and being sixteen inches broad.\*

The Toxodon appears, however, to have been a true Pachyderm, although provided with singular curved teeth, admirably adapted for gnawing, and with the orbit of the eye indicating a great power and extent of motion of the eye-ball in a vertical direction, together with other peculiarities offering considerable resemblance to the Rodents. In the anatomy of the ear, however, and the structure of the nasal bones, this singular animal differs entirely from the true Rodents, and approximates rather to the Cetaceans, apparently indicating the aquatic habits of the species, although there is nothing to render it probable that its extremities were rudimentary like those of the Whales. It was apparently provided with an expanded muzzle possessed of great sensibility, and probably of large size. This is indicated by the magnitude of the apertures for the passage of nerves and blood-vessels in the anterior part of the cranium.

The *Macrauchenia*, the ancient companion of the Toxodon in the great plains extending south of the Plata, was also a Pachyderm, but greatly resembled the Llama, and is remarkable for the extreme length of its neck, in which it is only exceeded by the giraffe.

This singular creature must have been extremely awkward and ungainly in appearance, for it seems to have had a body nearly as large and massive as that of the Rhinoceros

\* The existing Rodents are all exceedingly small, compared with these proportions. They comprise the squirrels, rats and mice, the marmots, dormice, beavers, hares, rabbits, porcupines, guinea-pigs, &c. and the water-hog of South America, all very small quadrupeds. Nor are any extinct species known greatly larger than those now living.

or Hippopotamus, supporting a neck three or four feet long, borne stiffly and upright, as in the Camel. The head and trunk were supported on long massive legs terminated by three-toed feet; and thus we may picture to ourselves this strange animal, a true Pachyderm in many points, but without a proboscis, stalking among the forests of South America, and feeding on the luxurious vegetation characteristic of the south-eastern parts of that continent.

But these extinct species, although presenting such remarkable analogies, and so many peculiarities of structure, are even surpassed in interest by their contemporaries of the order *Edentata*, at present represented in South America by the Sloth, the Armadilloes, and the Ant-eaters.

Of the order *Edentata*, the largest living species is the great Ant-eater, which attains the size of a Newfoundland dog; the next in size is the giant Armadillo, attaining about two-thirds that bulk, while the sloth does not exceed two feet in length from the snout to the tail. The two latter groups were, however, represented in former times by species whose dimensions, compared with their modern analogues, were most gigantic, some of them, indeed, rivalling in size the largest land mammalia.

Those extinct animals allied to the Sloth which formerly inhabited South America, have been referred to as many as four distinct genera, forming, according to Professor Owen,\* a natural family of phyllophagous, or leaf-eating *Edentates*, differing from the nearly allied family of which the Sloth is the representative by their short, powerful extremities, and thick strong tail, which plainly indicate a difference of habit, and shew them to have been con-

\* Description of the skeleton of an extinct gigantic sloth. London, 1843, p. 168.

structed for walking upon the earth, and not, like their modern congeners, climbing trees, and suspending themselves head downwards from the extremities of branches.

Of these four genera, the *Megatherium* is that which contains the species of largest dimensions, and which has been the longest known, and the *Megalonyx* is very nearly allied to it, but of smaller size. The *Mylodon*, although also of smaller size than the *Megatherium*, is especially interesting from the perfect knowledge that we possess of its anatomy, and the *Scelidotherium* is remarkable for the monstrous proportions of its posterior extremities, in which it far exceeds any known species.

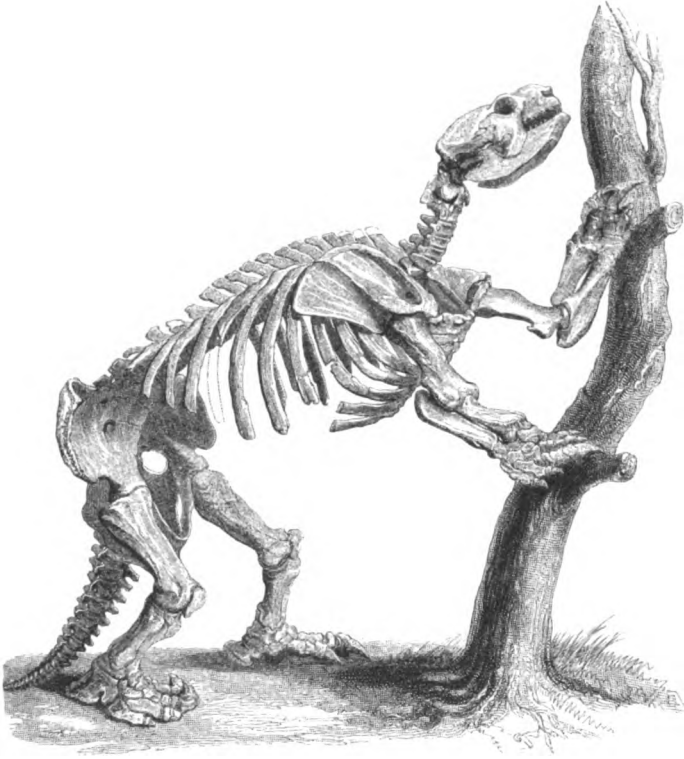
The dentition of all these animals, both in the form, number, and general composition of the teeth, and also in their minute structure and mode of growth, is the same, and is nearly identical with that of the Sloths. This structure is especially adapted for acting on the tender buds and leaves of trees, which are known to form the food of the sloths, and the similar modifications of the jaws and cheek bones in the Megatheroid animals must doubtless have been intended to assist in the work of preparing for the digestive organs similar vegetable substances.

The *Mylodon* \* (the anatomy of which has been the subject of minute and accurate description by Professor Owen, and which from the fact of its having been so admirably described, is the type to which all the other species of Megatheroid animals must be referred) was an animal

\* The nearly perfect skeleton of this animal, articulated under the careful superintendence of Professor Owen, forms one of the chief ornaments of the Museum of the Royal College of Surgeons. It has been described in the admirable monograph already referred to, and the figure in the next page is reduced from the lithographed engraving of the skeleton (by Mr. Scharf) which forms one of a large number of illustrations to the monograph.



whose massive proportions are so remarkable, and its general appearance so singular as to arrest the attention even of the common observer, as well as excite the surprise of the comparative anatomist.



MYLODON ROBUSTUS. OWEN.

*(One twenty-fourth the natural size.)*

The body of this animal is shorter than that of the Hippopotamus, but it is terminated by a pelvis as broad as and deeper than that of the Elephant, resting on two massive but short hinder extremities, terminated by feet set at right angles to the leg, and as long as the thigh bones.

A tail equalling the hind limbs in length, and as thick and strong in proportion as the tail of a kangaroo, helps to support rather than depends from the broad sacral termination of the pelvis, while some of the lumbar vertebræ are united by ankylosis to the sacrum, giving additional strength to the hinder extremities.

The ribs, of which there are sixteen pairs, are equal in breadth to those of an elephant, and the true ribs are clamped by massive and completely ossified cartilages to a strong and complicated breast-bone.

The fore legs are connected with the breast-bone by strong and complete clavicles, and the rotatory and lateral movements of these extremities are unobstructed by any prominences of bone which could interfere with their free motion in every direction; the bones of the forearm, which are comparatively long, are so unusually massive and powerful, that the feet, which are really broad and thick, appear relatively small. Both the fore and hind extremities are five-toed, and partly terminated by claw bones of great size and length, but on the whole they are short in proportion to their breadth.

The skull is smaller than that of an ox, but is long, narrow, and terminated by a muzzle singularly truncated. It is supported by a short neck of the usual number of vertebræ (seven), to which succeed sixteen dorsal vertebræ, remarkable for the broad and high spinous processes projecting from them, and having a uniform inclination backwards.

Such is a general description of this remarkable animal. The *Megatherium* exceeded it greatly in size, and differed in some of its proportions. Its length was as much as eighteen feet; the breadth of its vast pelvis was six feet, and the opening in the sacral vertebræ

for the passage of the spinal marrow is a foot in circumference, while the tail, where it was attached to the body, must have measured six feet in circumference.

The size of the thigh-bone in the *Megatherium* is nearly three times as great as in the largest known elephant; the bones of the instep and those of the foot, are of corresponding size, the heel bone projects backwards nearly eighteen inches, and the small bones of the foot, advancing at least as much forwards, supply a base to the enormous column just described, which is more than a yard in length and two feet across. The third toe is provided with a socket to receive a claw, the sheath of which measures thirteen inches in circumference, and the core on which the nail was attached is ten inches in length.

The teeth, both of *Megatherium* and *Myodon*, are peculiarly simple and very interesting in their structure. They are five in number on each side of the upper and four on each side of the lower jaw. In the *Megatherium*, each tooth is a four-sided prism, composed of an outer coat of bony matter, an inner layer of enamel, and a central mass of ivory, and the teeth are so placed in the jaw that the enamel plate of any one is opposed to, and works into, the softer ivory of the opposite one in the other jaw, so that a sharp grinding surface is constantly preserved. The lower part or fang of the tooth was hollow, and constantly growing through life, pushing forward the exposed end. The teeth of the *Myodon* are shaped somewhat differently from those of the *Megatherium*, and are rounder; the enamel also is on the outside, and the bony matter within; in other respects they too closely resemble each other to require separate description.

The general proportions both of the *Megatherium* and

Mylodon resemble those of the Elephant ; the body being relatively as large, the legs shorter and thicker, and the neck very little longer. The Megatherium may have had a short proboscis, but the Mylodon exhibits no mark of such contrivance.

The *Scolidotherium* was an animal much smaller than the Mylodon, and not exceeding in size some of the larger Ant-eaters, but in all its proportions, and more especially in the excessive magnitude of the bones of the hind leg, it was a true Megatheroid animal, exceeding even the Megatherium itself in the relative magnitude of this part of the skeleton.

It is an object of no little interest to deduce the probable habits of these Megatheroid animals, and their means of obtaining the food required for their sustenance ; and this is the more necessary ; because it has been argued by one set of naturalists, that these ponderous unwieldy animals must have climbed trees like the sloth,\* while others have supposed them to be capable of burrowing and hiding themselves in the earth.

Unquestionably, the fact which is most extraordinary and unusual in the anatomy of these animals is the structure and relative size of the extremities, and the enormous pelvis proclaims itself the centre whence muscular masses of great strength must have diverged to act upon the trunk, the tail, and the hind legs. The fore limbs were well adapted for grasping the trunk or larger branches of a tree, and the forces concentrated upon

\* The sloth, very improperly so called, is an extremely active animal, when roaming at will and passing from tree to tree in the vast and luxuriant forests of South America. It readily makes its way from branch to branch of adjacent trees, taking advantage of the numerous parasitical plants, which intertwine among the upper branches of the most lofty trees, and form a network readily traversed by this animal. On the ground the sloth is indeed helpless and awkward, but it is never willingly there, and only in fact when by some accident it has fallen from its support, or when the branch to which it trusted is broken.

them from the broad posterior basis are such as could well cooperate in the act of uprooting a tree, or wrenching off a branch.

But in order that the pelvis should possess stability and resistance equivalent to the due effect of the forces acting from it, it required to be bound down, as it were, and supported by members of corresponding strength. We accordingly find a thigh bone and a leg of the most unusual proportions, but exhibiting great strength and stability, and a tail so powerful, as to enable it to complete, with the two hind legs, a strong tripod, affording a firm foundation for the pelvis, and adequate resistance to the forces acting from that great osseous centre.

Viewing the pelvis thus as a fixed point, towards which the efforts made by the fore extremities were to be drawn, when the animal desired to uprend a tree, or wrench off a branch that bore its sustenance, the colossal proportions of this part of the body lose their anomaly, and appear in harmony with the other parts of the skeleton. The object of the great length of the hind-foot, and its prolongation backwards by a long heel, is also intelligible, as well as the proportions and construction of the tail, all of which form a combination of characters common to the Megatheroid family.

The long and powerful claws were also, no doubt, useful in the preliminary process of scratching away the soil from the roots of the trees to be prostrated. This operation having been duly effected, the long and curved fore-claws would next be applied to the opposite sides of the loosened trunk of the tree. "The tree being thus partly undermined, and further grappled with the muscles of the trunk, the pelvis, and the hind limbs, animated by the nervous influence of the unusually large spinal cord, would combine their

forces with those of the anterior members in the efforts at prostration. And now let us picture to ourselves the massive frame of the *Megatherium*, convulsed with the mighty wrestling, every vibrating fibre reacting upon its bony attachment, with a force which the sharp and strong crests and apophyses loudly bespeak; extraordinary must have been the strength and proportions of that tree, which, rocked to and fro, to right and left, in such an embrace, could long withstand the efforts of its ponderous assailant."\*

It is not a little remarkable that in the same locality from which was obtained the beautiful and interesting skeleton of the *Mylodon*, there was also found at the same time the carapace or covering of mail, belonging to a colossal animal allied to the *Armadillo*, but of dimensions and proportions quite as extraordinary as those of the *Mylodon* or the *Megatherium* itself. This animal has been described by Professor Owen under the name *Glyptodon*, the name being derived from the fluted or sculptured character of the tooth.

The *Glyptodon* was an Edentate animal, covered and defended by a shell or carapace, nearly resembling the coat of mail of some species of *Armadillo*, but was many times larger than the largest of those animals now existing. It was much more nearly allied to the *Armadillos*, however, than to the *Megatherium*, and appears to have connected the former group with the heavy-coated *Rhinoceros* of the *Pachydermata*.

The teeth of the *Glyptodon* differ in a marked manner from those of all known *Armadillos*, and exhibit a more complicated form than those of any Edentate hitherto discovered, indicating, it would seem, a transition to the *Pachydermatous Toxodon*, while the modifications of the

\* Description of the *Mylodon*, &c., p. 148.

extremities bespeak a similar approach to the ordinary Pachyderms. In the form of the lower jaw, however, and in the presence of a long process descending from near the cheek-bone, there is a remarkable resemblance and evident transition to the Megatherium.

The tessellated bony armour of the Glyptodon was not disposed in rings like that of the Armadillo, but made up of polygonal pieces, fitting one another accurately, and continuous over the whole of the upper part of the body and part of the tail, but only covering as with a roof the upper surface of the tail, (which is more remarkable for thickness than length,) and not encompassing it like the ordinary defence of the Armadillo. The armour is exceedingly thick and heavy, and when detached from the body it resembles a section of a large cask.\*

The bones of the extremity, very perfect remains of which were brought to England by Sir Woodbine Parish, are perhaps the most striking parts of the skeleton of this remarkable animal, and they have been admirably described in detail by Professor Owen.† They present to our observation the framework of a foot of such a structure and form as is without a parallel in the animal kingdom, but admirably contrived to form the base of a column destined to support an enormous superincumbent weight.

The short broad depressed phalangeal bones of the fore foot must have been encased in correspondingly short and strong hoof-like claws, chiefly subservient to support and progression, but which being associated with a rotatory condition of the radius, permitted the Glyptodon to apply its anterior extremities to all those purposes of scratching

\* The complete carapace of this remarkable animal is now in the museum of the Royal College of Surgeons.

† Geol. Trans., 2nd Ser. vol. vi. p. 88, *et seq.*

and digging to which the Armadillos, its nearest congeners, apply theirs.

From this short notice of one of the most singular and interesting groups of extinct species yet discovered, the reader may form some idea of the nature of the animals inhabiting the great plains of South America, at a period not perhaps so lately as since the introduction of man upon the earth, but certainly very little antecedent to that event, and when, possibly, our own island was peopled by elephants and huge ruminating animals wandering at will through extensive forests and across the plains, but exposed to the attacks of huge and powerful carnivorous animals, likewise no longer existing. And it must also be remembered that an analogy exists, and one of no slight importance, between the different races thus characteristic of different epochs in the two hemispheres. In our part of the world, the Pachydermata and Ruminants are still represented, and, indeed, the latter group still exhibit species which are, it is true, of smaller dimensions, but which are scarcely in other respects distinguishable from those whose remains are found fossil. In South America the Edentates, formerly of large size, are still, though on a much smaller scale, the predominating quadrupeds; and thus we see evidence of a degree of resemblance existing in the local development of groups which is well worthy of special note.\*

It is chiefly by considering phenomena of organic life in groups and series that philosophical deductions can be drawn as to the real nature of typical resemblance, and

\* The account given of the fauna of central Asia at the same or a somewhat earlier period, exhibits analogies too striking to be past over. The great land Tortoise, the gigantic fresh-water Gavial, the Sivatherium, the large Carnivora, and other remarkable extinct species, certainly indicate the same peculiarity.



for this reason it is that I have concluded my descriptions, as I commenced them, with such general accounts as I was able to offer, instead of detailed notices of specific differences. This is, I believe, the true view to be taken of Palæontology; and in this way only can be properly understood the important theorem that "fossils are characteristic of formations."

The singular fact that, at a period almost recent, Geologically speaking, and but little antecedent to the introduction of man upon the earth, there existed, in many parts of the world, groups of animals analogous to those still inhabiting the different districts, but greatly exceeding the present species in all their dimensions, would appear to be paralleled in those islands of the Southern Hemisphere, concerning the Palæontology of which we are just beginning to obtain some information.

New Holland, at this day the land of Marsupial animals, and of those still more anomalous ovo-viviparous quadrupeds the Echidna and the Ornithorhynchus, has yielded to the Palæontologist the fragments of large proboscidian Pachyderms, like the Mastodon or Dinotherium, occurring in bone caves, as in England and on the continent of Europe, but associated with fragments of gigantic Kangaroos, and other bones referrible to Carnivora which may have preyed upon them.

The island of New Zealand contains among its fossils the remains of a remarkable wingless bird, of proportions which may well be compared with those of the most gigantic mammal, and which seems to have been the representative, during the period we are now considering, of the small Apteryx, an animal still, though rarely, found living in the less frequented parts of the island. This bird, of which many portions have been

recently forwarded to England, has been described by Professor Owen, and named by him *Dinornis*. Several species have already been determined, varying in size very considerably, the largest being of the proportions of a Cassowary but much taller than the most gigantic Ostrich, while the smallest did not exceed the size of the Bustard. The general proportions of all of them are, however, nearly the same, indicating an animal much stouter, and more powerful in proportion, than the Ostrich, and entirely deprived not only of external wings, but even of any substitute for them that could be useful to the animal in assisting its locomotion.

The circumstances of the discovery of these birds—if so they must be called—are sufficiently interesting. Several years ago (in 1838) it was generally known in New Zealand, that the natives were aware of the former existence in the island of a monstrous animal which they called *Moa*, but the accounts received of it possessed so much of the marvellous, and were so interwoven with the superstitions of the natives, that nothing certain could be understood concerning it. It was generally supposed that only one individual existed, and that if any person ventured to approach the dwelling of this wonderful creature, he would be inevitably killed.

These accounts, although at first treated as fabulous, were soon rendered extremely interesting by the discovery of several very large thigh and leg bones, of dimensions far exceeding those of any animal known to inhabit the island. These bones were of a dark colour, and appeared to have entirely lost their oily matter; but within them, what little remained of the reticulated cells was nearly perfect; and although the bones at first discovered had been sawn across to be converted into hooks by the natives,

a leg-bone, eighteen inches long and proportionably thick, was found not long afterwards. Still, although visits were paid to the neighbourhood of the mountain in which the animal was said to live, no additional information could be obtained, and it seemed certain that no such creature could exist in the place. The bones were stated to be generally found after heavy floods, and as soon as the natives discovered that they were objects of interest, a considerable number were brought, chiefly consisting of the leg and thigh bones, and resembling those that had been before obtained. These were soon afterwards sent to England, and were the objects of minute description in a paper read by Professor Owen before the Zoological Society of London, and since published in their Transactions.

There are several interesting questions that suggest themselves with reference to these animals. In the first place,—Do they still exist, or how long is it since they may have ceased to exist? In answer to this, it is concluded, with every degree of probability, that they have indeed become extinct, but that their extinction has taken place since the island of New Zealand was tenanted by its present race of inhabitants: for, although there is nothing in native tradition to render it probable that any living man has seen one of them alive, yet the very fact of the existence of such traditions, alluding in so marked a manner to a gigantic bird, a former native of a district in which there are now no indigenous animals of large size, renders it probable that the final extinction of the race, already, perhaps, becoming diminished in number, was due to human agency. It has, indeed, been suggested that the name *Moa*, applied to the animal, being the same as that given by the natives of the Friendly and Sandwich Islands to the domestic cock, and the fact that the New Zealanders,

when speaking of the extinct monster, almost invariably say that it resembles the cock, the animal itself may have been a native of some island of the Indian Archipelago, where the Cassowary, its nearest analogue, is to this day found.

However this may be, the Moa, or Dinornis, is undoubtedly the most extraordinary animal yet discovered in the islands of the great Southern Ocean, and presents peculiarities of structure quite as striking as any of those species hitherto determined from the organic remains of Europe, Asia, or America. It adds, also, one more remarkable fact to those already recorded, with regard to the gigantic size of the vertebrata, at a period immediately preceding the introduction of man upon the earth ; for, although this bird, and some other animals, may have lingered on even till the peopling of the Southern islands, they must doubtless have flourished at a period long antecedent, and when the Megalochelys of Asia, the Megatherium of South America, and the great Deer and other Ruminantia of Western Europe, were the powerful lords of creation, and when, so far as we can judge, they formed the most important and powerful group of Mammals then existing on the earth.\*

\* Tasmanian Journal, vol. ii. p. 81, *et seq.*

## II. THE DESCRIPTIVE GEOLOGY OF CRYSTALLINE AND UNSTRATIFIED ROCKS.

### CHAPTER XLV.

THE NATURE OF IGNEOUS ROCKS AND SUCH SIMPLE MINERALS AS ENTER MOST COMMONLY INTO THEIR COMPOSITION.—  
GRANITE, GRANITIC ROCKS, AND PORPHYRY.



VIEW OF THE OBERLAND ALPS FROM THE SARNEN-SEE.

WE have hitherto considered only those Geological phenomena which have direct reference to stratification, the object having been to shew that the crust of the earth is formed, in great part, of a very extensive series of stratified deposits, due to aqueous deposition, lying one over another in regular order, and having a total thickness of many thousand yards.

But it may well be asked by the Geological student, in what way it has happened that all these various beds are now exposed to view, and what is the nature of the rock upon which this stratified mass of mechanical origin ultimately reposes? I have already, in an introductory chapter, had occasion to allude to this subject, and have shewn by a familiar illustration, how the different strata may have been exhibited at the surface, if, after their deposition, they were subjected to mechanical violence. In the present chapter I shall answer the latter part of the query which I have supposed to be suggested, and explain the nature of the mineral masses on which stratified rocks actually repose, or which, under certain circumstances, have pierced through them, as well as elevated them to the surface.

As a simple illustration of the change that has taken place by the action of subterraneous force, I have only to remind the reader of facts already recorded; namely, that stratified fossiliferous rocks are exhibited on the flanks of the highest mountains, and that they form a large portion of the whole surface of land, now elevated above the level of the sea. If it is clear from the nature of the mineral masses of which these beds are made up, and from their abundant fossil contents that they were formed gradually at the bottom of the sea, it is no less clear, either that the sea which once covered them must have sunk far below its former level, or that the whole mass of these rocks must have been elevated by subterraneous force.

The former hypothesis, that of the sinking of the sea level, is, however, utterly insufficient and unsatisfactory, because there is proof not only of one, but of frequent alternations of land and water on the same spot, and the mere retiring of the sea would not at all account for the most remarkable fact connected with these assumed disturbances,

namely, the high angle at which many beds are now inclined which must have been deposited horizontally, and the frequent disruption of strata, producing faults and other marks of mechanical action, which have been constantly observed in rocks of all geological periods.

There has, therefore, been disturbance subsequent to the deposition of stratified fossiliferous rocks, and the mechanical violence which has elevated them so that they have either not been covered up since by others of a more modern date, or which has destroyed all vestiges of such covering, has also exposed classes of rocks of a different kind, on which the fossiliferous strata ultimately rest.

Of these underlying rocks, there are two distinct series, one being crystalline, unstratified, and bearing no marks of mechanical origin, the other being stratified and of mechanical origin, but altered from the usual condition of fossiliferous strata, and containing no traces whatever, or hardly any traces, of organic remains.

Now, it must be clearly understood by the reader before we advance further, that the non-fossiliferous rocks of which we are about to speak, and which possess crystalline structure, are not all of the same date, nor are they in the present order of arrangement of their particles, necessarily older than the overlying stratified masses, although no doubt the actual materials of which they were elaborated may have been present before the deposition of the regular strata. This distinction must be carefully borne in mind in studying descriptions of igneous rocks, for it involves the important fact that mineral structure is of itself no guide in determining the relative position of any formation in the series, since a mere identity of mineral structure in two rocks from different localities, affords no proof whatever of contemporaneity of origin.

Perhaps I shall express my meaning more intelligibly in this matter if I illustrate it by an example:—By a careful investigation of the nature of the fossils, in all known formations, the Palæontologist is enabled to assert that the forms of animal and vegetable life, exhibited by the organic remains of any Geological period, are peculiar to that period, and characteristic of it; so that if, for instance, a group of fossils occurs in the Alps, identical in specific character with the fossils from the middle secondary rocks of England, we may assume with the highest degree of probability, and without any reference to mineral character, that the two formations were contemporaneous.\*

But, on the other hand, if the mineralogical Geologist, depending on his knowledge of Mineralogy alone, should find in the Alpine mountains a granite so closely resembling in mineral character the granite of some parts of Cumberland or Scotland as not to be distinguished from it, would he also be justified in assuming contemporaneity of formation? By no means. Granite, like every other crystalline rock, is confined to no Geological period, and can never, therefore, serve as a basis on which to found a complete Geological system. And so it is with the mineral composition of rocks generally; for the same causes, both immediate and modifying, which were at first employed in the formation of sandstones and limestones, have ever continued, and are

\* Such identifications have frequently been made in spite of mineralogical peculiarities. The slates of Glaris were in this way proved to be of the cretaceous period, although to all appearance of the oldest date. See vol. i. p. 184.

But there is after all no evidence so valuable or so absolutely satisfactory in the identification of strata of doubtful age, as that derived by actual sections, and, wherever it is possible, the certainty that attaches to the careful survey of a district by accurate mapping and detailed sections, should always be attained by the practical Geologist. Identification by groups of fossils is, however, in many cases, the only method available, and it is often quite unobjectionable; while resemblance of mineral character, on the other hand, is extremely unsafe, and can never be depended on as indicating any actual contemporaneity.



still at work ; the laws of attraction and of motion are, so far as the history of the world shews, unchanged and unalterable, while, on the other hand, those laws which have reference to the development of organic life involve a constant succession, the races which at one time flourished having gradually ceased to exist, and their places being supplied by others analogous to them but not identical. Thus it appears that in the course of its existence, as a fit habitation of organized beings, the earth has been tenanted by a succession not only of individuals, but of groups, each adapted to the circumstances of its development ; each, whether individual or species, performing its task, and then departing ; and each newly-introduced group exhibiting, on the whole, some new and more complicated organisation than was before known, until the time of the last great change when man, the crowning work of Creation, was placed upon the globe.

But although Mineralogy holds an inferior rank in Geology, when compared with Palæontology, the study of the mineral constituents of rocks must always be of real and practical interest, and it becomes of still higher importance when we turn to the description of crystalline rocks, and trace the work of nature in her vast subterranean laboratory. Wherever we are able to penetrate below that crust of stratified deposits, which so nearly covers up these workings, we find clear and distinct proof of extensive chemical action in which heat usually appears to have played an important part. There is little doubt, however, that the action of Electricity has been co-ordinate with that of heat, and thus these two powerful chemical agents, the one separating the particles of bodies so that they can move freely amongst each other, and the other directing and guiding the motions that ensue, according to

those remarkable, but ill-understood laws which regulate polar forces,\* constantly act together, and have produced in the lapse of ages those complicated and widely-extended phenomena which form the objects of study to the Geologist.

It is such phenomena, so far at least as regards mineral masses which exhibit distinct proof of igneous action, that we have now to discuss, and I shall devote the rest of the present chapter to the consideration of that part of Mineralogy, properly so called, which enters into the province of the Geologist.

Of simple minerals, indeed, the student of Geology takes but little heed in his researches into the structure of the earth, and a consideration of the peculiar forms and combinations of form observable in different minerals, although of the highest interest to the Crystallographer, is passed by with little notice by the Geologist, whose main object it is to investigate the nature and origin of the vast amorphous masses in which crystalline minerals are sparingly distributed. Notwithstanding this, however, it must be understood that whenever, as has frequently been the case, crystalline action has taken place on a large scale, it becomes a strictly Geological phenomenon, and in this way an intimate union exists between these two branches of natural science, the one of lesser generality (Crystallography) admitting of the direct application of analytical mathematics of a high order, and thus adding another link to the bond which unites Geology to the purely mathematical sciences.†

While I thus speak of Crystallography as one of the

\* See vol. i. p. 41, *et seq.*

† Did my plan admit of the consideration of the last and highest department of Geology, that in which Geological causes and the nature of those laws which have produced Geological phenomena are discussed, it would appear that there also the direct application of pure mathematics to Geology has been attempted, and with

sciences allied to Geology, and on which it is dependent, I would also be understood as giving but little encouragement to the mere pursuit of Mineralogy as a classificatory science, apart from the exact determination of crystalline forms; for the mere knowledge of the names and physical qualities of minerals can only be useful in a very limited degree, and has frequently been much overrated. To the practical miner, it is true, such knowledge is occasionally valuable, when acquired with reference to a particular locality; but for this very reason it is in a more general sense dangerous, for it is too apt to be empirical, and that which is a valuable and profitable rule in one mining district, may be utterly worthless and false in another.

I have thought it right here to express my opinion concerning Mineralogy and Crystallography, because I have mentioned both these sciences in the commencement of my work as allied to Geology. If, therefore, I may seem to undervalue the pursuit of technical Mineralogy, and speak very briefly concerning that part of Geology which has reference to it, I do so not unadvisedly, but for reasons which appear to me satisfactory.

I now proceed to the consideration of crystalline rocks, commencing with those which appear to form the skeleton as it were of our globe, and which we most usually find at the base, whenever we are able to follow the stratified rocks through all their gradations, and trace them to the mineral axis of mountain chains, whether in our own country or elsewhere.

no small share of success. It is due to Mr. Hopkins to state, that his valuable papers in the Cambridge Philosophical Transactions, and the Transactions of the Royal and Geological Societies, have mainly contributed to this great step, one result of which must be to check the progress of vague theories, suggested by superficial observers.

Amongst all these the granitic rocks of various kinds are unquestionably the most predominant and characteristic, and those which first deserve attention. They form the highest peaks, and the great centres or nuclei around which the altered and stratified rocks are collected in all the principal mountain chains, and they are often seen to burst forth in other districts, forcing their way through and penetrating into the fissures and cavities of the various overlying strata.\*



JUNCTION OF GRANITE WITH STRATIFIED ROCKS. ISLE OF SKYE.

The junction of granite with stratified rocks takes place in various ways, and may often be distinctly shewn to have occurred since the deposition of the rock. This is the case in the instance represented in the diagram, and it is there also clear, that the granite must have been injected in a fluid state. That granite and granitic rocks, (under which general title I include Syenite, Protogine, and the various kinds of Porphyries,) as well as the numerous rocks which may be classed together under the term Trap,† are all of igneous origin there can be no doubt, for it is proved by their being injected into the narrow crevices of fractured

\* The Alps exhibit numerous examples of this, the mineral axis of the chain making its way through the stratified rocks in many places, and producing the most beautiful and picturesque scenery. I have given at the head of this chapter a view which, although not very characteristic, illustrates the nature of this scenery.

† This word, derived from the Swedish *trappa*, signifying a stair, was originally applied to rocks which on exposure to the air assumed a step-like shape. Its use has since been very much extended, and it is now understood by Geologists to signify a very large class of rocks of igneous origin often injected into veins or dykes, and often erupted and spread out on the surface of other rocks.

strata, altering, as if by the action of fire, the rocks, whether fossiliferous or not, with which they come in contact.

Many instructive and very striking proofs of the perfect fluidity of these rocks when injected are seen in various parts of England, more especially near the Land's End, in Cornwall, and perhaps still more abundantly in Scotland.



JUNCTION OF TRAP WITH STRATIFIED ROCKS. COAST OF TROTTERNISH.

The diagram annexed exhibits an instance in which an unstratified rock has been forced through another, which is regularly stratified, and has penetrated it in a horizontal direction, filling up fissures and cracks in the stratified rock, and being gradually lost sight of at a distance from the central mass. In this state the injected rock may assume a distinctly stratified appearance in a section, so that it would be quite impossible to determine, from the examination of a small portion, what may have been the origin of the igneous rock. Another appearance, that of a mass of trappean rock bursting through and overlying a regularly deposited stratum, is exhibited in the subjoined diagram,



TRAP BURSTING THROUGH AND OVERLYING SANDSTONE, NEAR SUISHNISH, ISLE OF SKYE.

and both this and the former may be considered as representing large classes of similar phenomena, observable in almost every district in which igneous rocks have forced

their way to the surface through the regularly stratified deposits.

The Granitic and Trappean rocks are made up, for the most part, of some combination of the following simple minerals; and as the list comprises almost all those that enter abundantly into the composition of mountain masses, it is advisable that the Geological student should be familiar with their general aspect and different appearances, and be able to identify them. These minerals are, *Quartz*, *Felspar*, *Mica*, and *Hornblende*, or *Augite*.

QUARTZ is a mineral too well known, and too widely extended to require any detailed description. It occurs sometimes crystalline, and sometimes massive,\* and is often seen forming veins in those unstratified rocks, such as granite, which contain a large proportion of it in their ordinary structure.

FELSPAR is an earthy mineral, occurring both massive and disseminated. There are several varieties of it, all of which scratch glass. Their structure is always laminated; they yield with more or less ease to mechanical

\* The term *massive* in mineralogy is applied to those minerals which possess regular internal structure without any particular external form. When a mineral, whether crystallized or otherwise, is found here and there embedded in a mass of another substance, it is said to be *disseminated* in the mass. The *structure* of a mineral relates to its internal characters. It may be either *crystalline*, cleaving into regular forms, which present smooth, brilliant, and parallel surfaces; or *imperfectly crystalline*, when the surfaces are neither smooth nor parallel, but rough and uneven, or undulating (such as all fibrous minerals, whether massive or not); while all such minerals as have no determinate structure (those, for instance, which are granular, splintery, &c.) may be included in the term *indefinite*, and are divided into two groups, those in which the separate particles may be distinguished, and those in which they are not apparent, even with the aid of the microscope. These latter are called *compact*, and the others, coarse or fine-grained, according to circumstances.

The *cleavage* of minerals is a term used to express the fracture of such as have natural joints, possess a regular structure, and may be cleaved or mechanically divided indefinitely by the application of force, into fragments having definite angles.

cleavage, and they are composed of variable proportions of silix, alumina, and potash, with a little iron. Felspar is one of the most abundant minerals in nature.

MICA is a well-known mineral, which splits readily in one direction. It occurs abundantly in granite, and in several of the best known igneous rocks. The plates of which it is composed are readily separated, and are flexible and very elastic; they are also brilliant, and translucent, so as to be capable of being used instead of window-glass.

HORNBLENDE is also a mineral abundantly distributed in several igneous and altered rocks. It is characterised by its dark green or velvet black colour, its peculiar form of crystallisation, and its shining lustre. It is opaque, and tough, but yields pretty easily to the knife. It contains a considerable proportion of iron, (the blacker varieties especially,) combined with silica, alumina, lime, and magnesia. It has a distinct cleavage, and a coarse, uneven fracture, and yields a peculiar smell when breathed upon. *Augite* is another form of the same mineral, distinguished from Hornblende by its higher lustre, greater hardness, and conchoidal fracture, and it is more frequently found in volcanic rocks of comparatively modern date, than in the oldest igneous and altered rocks.\*

\* The following are the mineral constituents of the most common forms of felspar, mica, and hornblende. Quartz consists of nearly pure silica, with a trace, however, of alumina, and sometimes of iron.

	Felspar.	Mica.	Hornblende.	Augite from Etna.
Silica . . .	66·75	48·00	42·00	52·00
Alumina . . .	17·50	34·25	12·00	3·33
Lime . . .	1·25	—	11·00	13·20
Potash . . .	12·00	8·75	a trace.	—
Magnesia . . .	—	—	2·25	10·00
Oxide of iron .	0·75	4·50	30·00	14·66
Oxide of Manganese	—	0·50	0·25	2·00
Water . . .	—	—	0·75	—
	98·25	96·00	98·25	95·19

JAMESON'S *Mineralogy*.

## GRANITE AND PORPHYRY.

GRANITE is a rock composed of variable proportions of felspar, quartz, and mica, intimately joined together, often separately crystalline, and without any base or ground. Felspar is usually the predominating rock, but it is sometimes equalled in quantity by quartz. In some varieties the quartz is wanting, and sometimes the mica; while occasionally this latter ingredient is replaced by hornblende, (in which case the mass is called *Syenite*,\*) and sometimes by talc, or a peculiar form of that mineral, called *chlorite*; and in this latter state, it has received the name of *Protophane*, and is very abundantly exhibited in the higher peaks of Mont Blanc.

The size of the constituent parts of granite, and granitic rocks, is exceedingly variable, but sometimes so constant in a particular district, and possessed of such peculiarities of appearance, as to be readily identified.† In some places, as in Cornwall, in the mountains of the Fichtelgebirge, and elsewhere, it contains crystals of felspar several inches in length, and masses of quartz of nearly equal size. Sometimes the mica is found in plates upwards of a foot square; in other varieties again, the grains are so small that the granite appears nearly compact; and occasionally, the quartz is separated and exhibited in very large masses, irregularly enveloped by felspar, and containing small crystals of mica disseminated through it. It rarely happens that all three materials are perfectly crys-

\* So called from the ancient Egyptian quarries of Syene. The beautiful red granite, of which the Egyptian statues, and other sculptures, are made, is a *Syenite*.

† This is the case, for instance, with the granite of Shap in Cumberland, which is so peculiar as to be easily recognised, even in boulders which have travelled nearly across England.



talline ; but even this occurs in some mountain districts, and is especially remarkable in the granite of Mount St. Gothard.

The structure of granite is various. It is occasionally met with in bands or strata, and is sometimes columnar ; but it more frequently occurs in large irregular bosses, forming the higher peaks of mountains, or injected into fissures of the rocks it has been forced through. Owing to the variable proportions of its component parts, and the different conditions of the felspar, it resists in some places for ages the destroying effects of the weather, forming the *aiguilles*, or needles, on the tops of the highest mountains, or, as in the case of the ancient Egyptian



obelisks, handing down to distant ages the lightest marks of the chisel, and the smallest hieroglyphic carved upon its surface. Other varieties are almost immediately disintegrated on exposure to atmospheric action ; and these different kinds occasionally appear within the compass of a very limited district, and sometimes present remark-

able and interesting phenomena of unequal decomposition, such as are seen in the logan, or rocking stones of Cornwall, an example of which is represented in the annexed woodcut.\*

The lamellar appearance thus observable in the Cornish granite often seems to be referrible to a peculiar structure, and has sometimes been mistaken for stratification, but in lofty chains of mountains (such as the Alps of Switzerland and some parts of the Cordilleras of the Andes) a somewhat similar aspect is presented, owing to the abundance and uniform direction of the plates of mica. The existence of any appearances of this kind, the coarseness of the grain, the regularity in the crystallization of the component parts, and the colour of the felspar, are all phenomena worthy of attention, and may occasionally assist in determining the relative age of a formation.

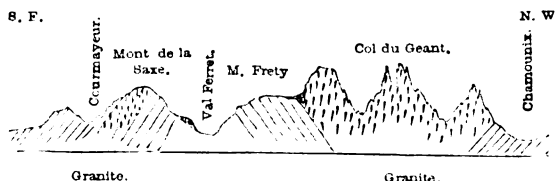
The shape of granite mountains may readily be understood to depend on the degree of hardness and resisting power of the rock. Where that is of a loose texture, the hills have a rounded form, as in Cornwall, and still more remarkably in the Fichtelgebirge, already referred

\* In the Fichtelgebirge, a group of granitic hills in Bavaria, on the frontiers of Bohemia and Saxony, there is a remarkably beautiful and picturesque instance of decomposing granite. It is called the Louisenberg, and I can myself speak to the accuracy of the following graphic description of it, extracted from Murray's "Handbook for Southern Germany," 2nd edit. p. 88. "The road to the Louisenberg lies along the slopes of a hill, copiously strewn with loose masses of granite, increasing in size and quantity as you advance, until at length the hill itself seems to consist of nothing else but disjointed fragments piled in heaps over one another. Such a vast pyramid of loose rock might have furnished the Titans with ammunition when storming Jupiter in Olympus. If you begin at the bottom of the hill, and climb to the top, or compass it round, you still find nothing but rocks in pieces, tumbled about in all directions, and the result is a kind of labyrinth, in which one may wander about for hours, sometimes creeping for many yards together through caves, dark, or barely admitting a few gleams of light between the interstices of the huge superincumbent masses which form their roof; at others, threading narrow clefts, or scrambling over projecting masses, to the summit of the hill, which is itself a detached block."

to. In other cases, as in Mont Blanc, the hard and indestructible granite rises in the form of peaks or deeply serrated ridges, and thus produces the bristled and denticulated aspect so peculiar to many mountain districts. The valleys in granite countries are generally deep and narrow, and their sides often resemble immense perpendicular walls.\*

Granite occurs in almost every mountain district in the world, and is also very frequently found occupying large tracts of table-land, and other level country. In the British Isles, it forms the central nucleus of the Grampians, and many of the Western Islands of Scotland. It appears, also, in the lake district of Cumberland and Westmoreland, and in the Isles of Man and of Anglesea. In the centre of England, small patches have forced their way through the New red sandstone of Worcestershire and Leicestershire, forming the Malvern Hills, and the hills of Charnwood Forest; and in Cornwall the same rock is exhibited in six principal masses, and is again repeated in

\* I subjoin a section across a part of the chain of Mont Blanc, in which the granite (or protogine) is seen not only forming the high peaks of the Col du Géant, but interstratified with the altered rocks of the Montagne de la Saxe, on the south side of the chain near Courmayeur.



SECTION ACROSS THE CHAIN OF MONT BLANC.

The above section is also interesting as shewing the sedimentary rocks dipping under the granite on both sides of the principal axis, an appearance not peculiar to this district, but remarkable, as it indicates the eruption of the fluid granite under circumstances not very easy to understand. The section is taken from the admirable work on the Savoy Alps, recently published by Professor Forbes of Edinburgh.

the Scilly Islands. Granite also forms the central axis of the great Scandinavian chain, and of the Alps, the Pyrenees, the Carpathians, and the Ural chain. It is met with in the Caucasus, and may be traced, almost without interruption, thence to the Himalayans, and also to the north-easterly chain of Asia, called the Altai mountains. Over the whole peninsula of India it appears to be spread out very extensively at no great depth below the surface;\* and it is known to occur in Upper Egypt, and in the neighbourhood of the Cape of Good Hope. In America, it occupies a subordinate position among the rocks of the Cordilleras of the Andes; but it abounds in the lower mountains, and descends even to the plains and the coast of Peru. In North America, as in the Southern Continent, it ceases to characterise distinctly the central mineral axis, but is found on the flanks of the mountain chains.

PORPHYRY is a word made use of by Geologists to designate a compound rock, having a base in which the other constituent parts are embedded either in the form of grains or crystals. The base may be felspar, granite, or almost any other rock, and the porphyry is named according to the nature of the base. The original meaning of the word has reference to a red variety; but the colour is now not considered essential, nor is the use of the term limited to any peculiarities of mineral composition.

Porphyry is very rarely stratified,† but is usually massive and traversed by numerous accidental fissures, and

\* The mineral called laterite, so abundant in the western part of Southern India, appears to be nothing more than the result of a complete disintegration of granitic rock.

† Among the most remarkable exceptions to this, may be mentioned the alternating masses of slate and porphyry which are found in the lake district of Cumberland and Westmoreland, rising into the highest and most rugged mountains

it occasionally fills up broad cracks or dykes in other rocks. It is frequently met with associated with other igneous rocks, but is not so abundantly distributed as granite. Some extremely rich metallic veins are worked in porphyry, more especially in the mining districts of South America.\*

Some of the rocks named porphyritic are occasionally porous, like modern lavas, only the cavities formerly existing have been filled up since by mineral substances, which have penetrated them by infiltration. These cavities, or rather the minerals with which they are filled, being often oval or almond-shaped the name *amygdaloid* has been given to the rocks containing them, and it will readily be understood that the base of such a rock, as well as the mineral that has filtered in, may present very considerable and important varieties. Amygdaloidal cavities, in fact, furnish the mineralogist with a great abundance of interesting siliceous and calcareous minerals.

There are some other igneous rocks, which are com-

of the whole region. "These two distinct classes of rock are piled upon one another in tabular masses of such regularity, and are so interlaced and blended that we are compelled to regard them as the effects of two distinct causes acting simultaneously during a long geological period. The igneous portions present almost every variety of felstone (compact felspar), and felstone porphyry, sometimes passing into greenstone, and rarely into masses with a structure like that of basalt."—Professor Sedgwick's *Letters*, Wordsworth's *Cumberland Lakes* 2nd edit. p. 224.

\* Porphyry and Syenite are stated by Humboldt to be the predominant formations of South America. They are intimately associated with trachyte (a rock that will be described in a subsequent chapter, when speaking of volcanic rocks and basalt), and they repose either on primitive rocks immediately, or on clay slate, in which latter case they are often metalliferous. These porphyries are, however, of modern date, compared with the granitic and other Plutonic rocks we have been chiefly considering in this chapter, and belong rather to the group of trachytic lavas, which so greatly abound throughout a considerable portion of the Cordilleras of the Andes. A minute account of these rocks will be found in M. Humboldt's *Geognostical Essay* (English Translation, London, 1823, p. 151, *et seq.*)

monly spoken of amongst Geologists, and which, therefore, deserve mention in this place. Thus, syenite and felspar-porphry both pass into a rock called *green-stone*, when the quartz which usually enters into their composition is absent; and greenstone, again, by the absence of felspar, becomes *hornblende-rock*; while hornblende-rock, united with quartz, is called *hornstone*. *Claystone* is a compact rock, resembling indurated clay, and contains scattered crystals of felspar and quartz, the base being earthy felspar. *Serpentine* is a greenish rock, containing magnesia, combined with a green-coloured brittle mineral called *Diallage*, and it is sometimes fine grained. Masses of actual Diallage, with indistinct marks of crystallization, are also called Serpentine.

All the rocks that have been described in the present chapter, together with others which I have not thought it necessary to allude to, are sometimes spoken of as one group, under the name **HYPOGENE**, or **PLUTONIC**, and, together with a large class which I shall describe in the next chapter, were formerly designated **PRIMARY**. The term **Primary** is objectionable, because it assumes that the rocks so called are of more ancient date than the overlying fossiliferous deposits; whereas we now know that in many cases the granite must be more recent than even the newer Secondary formations. The word **Plutonic**, as it merely intimates the origin of the rocks, is evidently synonymous with 'igneous,' in the sense in which I have hitherto used the latter word; but **Hypogene**, an expression introduced by Mr. Lyell, is a term of greater importance, as the use of it involves to a certain extent the reception of a theory which well deserves notice, and which is connected with those views of metamorphic rocks which we shall presently have to consider.

Mr. Lyell proposes to include under the one name of 'Hypogene,' all those unstratified rocks which offer no appearance of mechanical origin, together with those large classes of stratified rocks which do not contain at present any mark of organic remains, owing to changes which are assumed to have taken place in their intimate structure, since their original deposition. "These all have certain characters in common," says Mr. Lyell,\* "and it is, therefore, convenient that the class to which they belong should receive some common name,—a name which must not be of chronological import, and must express, on the one hand, some peculiarity equally attributable to the Plutonic and *altered* rocks, but which, on the other hand, must have reference to characters in which those rocks differ, both from the volcanic, and from the *unaltered* sedimentary strata. I propose the term 'Hypogene' for this purpose, as implying the theory that granite and altered rocks are both *nether-formed*, or which have not assumed their present form and structure at the surface. All stratified rocks, indeed, must have been deposited originally at the surface; but they could never have acquired a crystalline texture, unless acted upon by heat, under pressure, in those regions, and under those circumstances, where the Plutonic rocks are generated."

Such are Mr. Lyell's reasons, and such is his view of the subject in reference to this term. Without entering into the discussion of these theoretical views, or their bearing upon the peculiar opinions held by Mr. Lyell, it appears to me that the term he proposes may be safely and conveniently employed. It well expresses at all events, the very important fact, that beneath the long series of fossiliferous and stratified rocks, however far that series may

\* Principles of Geology, third edit. vol. iv. p. 290.

extend, there are yet other rocks, non-fossiliferous, but of mechanical origin, and presenting no important difference in mineral character distinguishing them from fossiliferous rocks that is not readily accounted for by assuming the subsequent and long-continued action of heat upon them. It also affirms that the rocks of this altered series only appear above the distinctly igneous or Plutonic rocks; assuming that between the regularly stratified fossiliferous deposits and those which have been mainly active in uplifting and disturbing them there is an intermediate group, partaking of the character of both, and exhibiting to us something of the nature of those great depths below the earth's surface at which changes take place in rocks, and where those rocks which were originally formed by deposition from water are brought by degrees into the condition of crystalline masses, exhibiting no appearance whatever of mechanical origin.

With these views, therefore, I shall make use of the term Hypogene, and employ it, together with the equally definite and useful word, Metamorphic, while discussing the nature of those non-fossiliferous masses which have now to be considered. I do not, however, wish to be understood as assuming the truth of any theoretical views in thus employing the most convenient terms to express my meaning, and I trust that the reader, should he be inclined to question the theory, will not for that reason think it necessary to doubt the facts.



## CHAPTER XLVI.

METAMORPHIC OR ALTERED ROCKS.—GNEISS.—MICA-SCHIST.—  
CLAY-SLATE.—THE STRUCTURE OF METAMORPHIC ROCKS.



AUGHRISS HEAD, COUNTY SLIGO.

IN making use of the term Metamorphic, and designating by it a particular class of stratified, but non-fossiliferous rocks, I have already stated that I do not bind myself, or the reader, to any theoretical views on the subject; I mean simply to express the fact that these rocks have been changed, because in many instances there is direct evidence of such change having taken place, and in many more where direct evidence is absent, there is indirect, but sufficient proof of the fact.

The principal metamorphic rocks which I shall speak of in this chapter are, *Gneiss*, *Mica-schist*, and *Clay-slate*; and I shall chiefly confine my attention to these, because, with the exception of metamorphic limestone and quartzite, (of which a very short description is sufficient,) they may be made to include most of the various rocks which were formerly described under the term "Stratified primary formations."

No distinct order of superposition can be traced in these formations, and I shall describe them in the order in which they are mentioned above, as being that most convenient, and to which Geologists are most accustomed.

#### GNEISS.

The word Gneiss is of Saxon origin, and since the time of Werner it has been understood to apply to a crystalline compound of quartz, felspar, and mica, distinctly stratified, and very widely distributed wherever granite occurs, but more especially abundant in Scotland and the Scandinavian range, and in Bohemia, Silesia, and the metalliferous mountains of Saxony.

Although the materials of Gneiss are the same as those of granite, the proportions of the component parts are often different, the mica being more, and the felspar less abundant; the quartz, also, is usually in smaller grains than the felspar.

I have mentioned that gneiss is distinctly stratified; its planes of stratification are, like those of other stratified rocks, nearly parallel to each other, and sometimes, also, parallel to the surface of the granite or other Plutonic rock on which it rests. In other cases, and these are not extremely rare, the transition is perfect from the altered to the

igneous rock ; and the gneiss, composed of the same materials as the granite, and its texture being equally crystalline, gradually loses its only distinctive character, that of stratification, and passes into a granitic rock, in which no trace of stratification remains.

These facts, the one tending to prove the mechanical origin of the rock, and the other as clearly indicating igneous action, can only be reconciled by supposing that the materials of gneiss, and in some cases of granite also, were derived from the degradation of granitic rocks, originally deposited from water in the usual form of aqueous strata, and that these strata have subsequently been altered by subterraneous heat, so as to assume a new texture.

Among the most interesting phenomena of gneissic rocks to the English Geological student, are those which occur in Scotland and Ireland, occupying a very important part in the Geology of those countries. Over a considerable portion of the main land, and in most of the western islands of Scotland, gneiss is the predominant and fundamental rock ; and many appearances are presented on the cliffs, and in different parts of the coast, exceedingly instructive, and indicating clearly the magnitude of those operations of nature, which have resulted in the contortions and intricate flexures with which these rocks abound.

The gneiss of Scotland exhibits two principal varieties,\* the one granitic, indestructible, and the presence of which is marked on the surface by the peculiar nakedness of the countries composed of it ; the other, schistose, passing into mica slate, and covered by a soil scarcely different from that in which the latter rock is predominant. Both varieties conform, in some measure, to the general bearing

\* Macculloch's Western Islands of Scotland, vol. i. p. 216, *et seq.*

of the Scottish strata, and both are occasionally intersected by granite veins, which are rarely absent for any considerable space, while the contortions of the gneiss are always proportioned to the number and importance of the veins which it contains. In some instances, as on the north-west coast, near Cape Wrath, the veins are so abundant as nearly to exclude the original rock, and the fragments of gneiss do not seem to form a twentieth part of the whole mass, while the progress of the different veins, and their effects in producing the disturbance, are perfectly distinct.

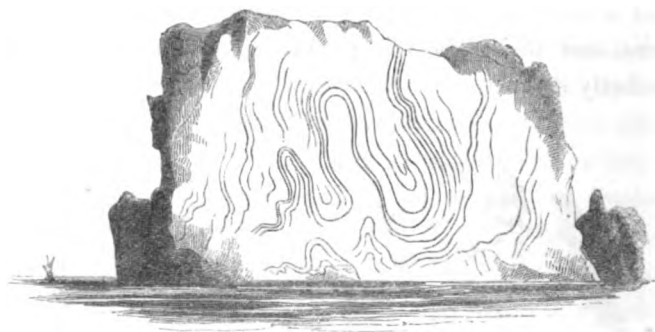


GNEISS TRAVERSED BY GRANITE VEINS, CAPE WRATH.

The picturesque features of gneiss present every possible variety ; a broad expanse occupied by this rock sometimes extending over considerable tracts, and being only relieved in its savage monotony by occasional pools of water or patches of bog, while in other districts it forms wild and rugged hills, assuming a mountainous character, and displaying broken and craggy faces of rock.\*

\* "Loch Hourn is particularly distinguished by the height and ruggedness of the hills that surround it, among which the district of Knoydart is pre-eminent, forming, indeed, the wildest tract in all Scotland."—Macculloch, vol. i. p. 217.

There are few more remarkable geological phenomena than the indications of former perfect flexibility in certain rocks which are now extremely hard, and which would not admit of the slightest bend without fracture. Such phenomena are especially characteristic of the gneiss in some of the western islands of Scotland, and nowhere more so than in the Isle of Lewis. I subjoin a diagram



CURVATURES OF GNEISS, NORTH WESTERN EXTREMITY OF LEWIS.

in which some of these contortions are exhibited. The rock which is here sketched is above fifty feet high, and is called the Butt of Lewis. Dr. Macculloch observes: "Imagination can scarcely conceive an intricacy of flexure of which a resemblance could not be found in Lewis, which far surpasses all the other western islands in the variety and distinctness of these phenomena.\*"

Gneiss, as well as granite, admits of several varieties, arising from the substitution of other minerals for either the quartz, the felspar, or the mica, of which it is usually composed.

The mica, for instance, may be replaced by talc, forming

\* Loc. cit. p. 191.

what is sometimes called stratified protogine; or hornblende may be superadded to the ordinary materials, forming a syenitic gneiss, and many other changes may take place, none of them, however, interfering with its general appearance or geological character, and none requiring separate or detailed description.

## MICA-SCHIST.



VIEW OF CLARE ISLAND.

Mica-schist, or slate, is, next to gneiss, one of the most abundant of the metamorphic rocks. It differs from gneiss in its more slaty structure, and in the absence of felspar. Mica is the predominating ingredient, and is often disposed in continuous plates and not in distinct scales, and the quartz either occurs in thin lenticular masses, interposed between the plates of mica, or is distributed in beds or veins sometimes becoming more abundant than the mica, and passing into quartz rock.\*

Mica-schist not unfrequently passes into gneiss, more

\* Quartz rock is an aggregate of grains of quartz, either in minute crystals, or slightly rounded, and occurring in regular strata, associated with metamorphic rocks. It is sometimes called *quartzite*. Compact quartz is also found associated with this rock, as well as in veins in gneiss, mica, schist, and clay-slate. — See Lyell's Elements of Geology, 2nd edit. vol. ii. p. 383.

particularly at the junction of the two rocks, or at the junction of mica-schist with granite. It also passes occasionally into another rock, called chlorite-schist, chlorite being substituted for the mica; and either in this way, or directly, it occasionally graduates into clay slate, and thus forms the link which appears to connect granite with a rock from which it generally differs so essentially. The physical features of mica-schist are nearly the same as those of clay slate, but it more frequently contains minerals and metalliferous veins. It is met with in certain parts of Scotland, but is greatly more abundant in the west and north-west of Ireland, and is widely distributed not only on the continent of Europe, but in the United States of North America, and also in various parts of Africa and Asia. The vignette at the commencement of this chapter, and that in the preceding page, both of them illustrate Irish scenery in which this rock greatly predominates.

#### CLAY-SLATE.

Clay-slate may be looked upon as a rock common to the metamorphic and fossiliferous series, and offering the strongest argument in favour of the metamorphic theory. It resembles indurated clay or shale, and may consist either of the same ingredients as gneiss, or of an extremely fine mixture of mica or talc with quartz, but it usually contains a considerable proportion of argillaceous matter mixed with a still larger proportion of silica, a little iron, and some of the alkaline earths. It is extensively developed in Cumberland and the lake district, in many parts of North Wales, in Devon and Cornwall, in Ireland, and in Scotland. The same mineral is also found wherever there is any considerable extent of Plutonic and altered rocks, not only on the continent of Europe, but in Asia, Africa, and America,



and I have already had occasion to observe that there are some rocks in Switzerland having this peculiar mineral character, but referred to the Cretaceous period. Clay-slate is not unfrequently fossiliferous, but the fossils are often much altered, and only observable in the narrow lines of parting between two beds.



VIEW OF SKIDDAW AND THE NEIGHBOURING MOUNTAINS.

The Cumberland slates, which are spread over a large area, are best seen in the coombs and peaks surrounding Skiddaw Forest, and in the grassy mountains between Derwent Water and Crummock Water.\* The formation is chiefly composed of dark glossy slate, containing no organic remains, and rarely affording roofing slate. It passes occasionally into a micaceous flagstone, and alternates, though rarely, with coarse gritty beds.† The whole is surmounted by a great series of roofing slates which alternate with conglomerates and bands of porphyry, and with other igneous rocks.

The slates of North Wales form a more extensive group than those in the lake district ; and the Penrhyn quarries,

\* See vignette, vol. i. p. 162.

† Sedgwick, *loc. cit.* p. 229.



in the neighbourhood of Bangor, have long been celebrated for their great extent, and the magnitude of the rock exposed. In 1837, the excavation extended 700 yards in length, 300 in breadth, and 90 below the natural surface. The slate is of a peculiar dark blue colour, it is perfectly fissile, having a regular cleavage quite distinct from the bedding, and the beds are occasionally cut through by dykes filled with igneous rock.\* The slate immediately in contact with the trap is generally found to have lost its fissile properties and become flinty, and its colour is also changed from purple to black; but these effects are rarely traceable for more than two or three feet from the igneous rock.† Much of the slate in North Wales is fossiliferous, but the shells are comparatively rare, and often injured.

In Devonshire and Cornwall the slates are much more fossiliferous, and the fossils, on the whole, are in better condition than either in Cumberland or North Wales. The slates not unfrequently contain calcareous matter, and they are sometimes perfectly mechanical in structure, but often crystalline,—those of Cornwall being more frequently so than those of South Devon. Scotland possesses many localities in which roofing slate abounds; and Ireland is also well provided with that useful mineral.

\* The slate here alternates with a coarse sandstone, not parallel to the beds, and in one part the sandstone is exhibited on both sides of an anticlinal axis, as represented in the annexed diagram. Throughout the whole, however, the cleavage has the same direction, clearly proving that this last change has taken place not only since the consolidation of the whole rock, but also since some very considerable disturbances have altered the direction of the beds.



BEDDING AND CLEAVAGE IN THE PENRHYN SLATE QUARRIES.

In the diagram the larger arrows above represent the direction of the dip of the beds, and the smaller ones below the dip of the cleavage planes.

† Proceed. Geol. Soc. vol. ii. p. 449.

I have not here separated the slate formerly called *primitive*, from that designated by the older Geologists *transition*. The two scarcely differ in any point of mineral structure ; they are both common in the same localities, and their only distinctive character seems to be, that the one series (the primitive) is non-fossiliferous, and is less carburetted and earthy in its general aspect than the supposed newer variety. Since, however, slate rocks belong to no Geological period, but are abundantly developed in the Middle and Older Palæozoic rocks, and occasionally, also, in the later Secondary, the mere chance occurrence of fossils can be no guide, and the supposed difference in mineral character is not at all sufficient to authorise a distinct grouping.

Having thus explained the general phenomena of appearance of these metamorphic rocks, I must now refer the reader to a former chapter, in which I have alluded to the subject of joints and cleavage, explaining them as changes that have taken place in the internal structure of rocks by forces which have acted since their deposition.\* Changes of this kind, indeed, are not entirely due to igneous action, although, doubtless, in many cases they were greatly modified and assisted by heat : but they are known to have been often superinduced in secondary rocks without the destruction of their organic remains, all marks of which the direct application of heat has been found to obliterate.

What is most remarkable and interesting in the cleavage planes of slate rocks, is the uniformity of their direction throughout a great extent of country, where the rocks themselves are twisted into every variety of contortion. In North Wales this is most remarkably the

\* See *ante*, vol. i. p. 38, *et seq.*

case ; and Professor Sedgwick has stated,\* that “a rugged country, more than thirty miles in length, and eight or



SLATE ROCKS ON THE LEFT BANK OF THE TOWEY.

ten miles in breadth, stretching from the gorge of the Wye, above Rhaiadr, to the upper gorge of the Elan and the Towy, and to the hills west of Llandovery, exhibits, on a magnificent scale, thousands of examples like that figured in the accompanying diagram.† The whole region is made up of contorted strata, and of the true bedding there is not the shadow of a doubt. Many parts are of a coarse mechanical structure, but subordinate to them are fine crystalline chloritic slates ; but the coarser beds and the finer, the twisted and the straight, have all been subjected to one change, and crystalline forces have re-arranged whole mountain masses of them, producing a beautiful crystalline cleavage, passing alike through all the strata. And again, through all this region, whatever be the contortions of the rocks, the planes of cleavage pass on generally without deviation, running in pa-

\* Geol. Trans. 2nd Ser. vol. iii. p. 477.

† The diagram represents two portions of a series of finely contorted strata of hard, greenish slate from the rugged mountains on the left bank of the Towy, a little below Fany. Many of the beds are very quartzose, and are obviously of sedimentary origin. The more slaty portions have their beds defined by stripes upon the cleavage planes, and the whole contorted stratification is perfectly obvious. Throughout these sections, which extend nearly a mile in length, as well as through all the neighbouring chain, the cleavage planes preserve an almost geometrical parallelism, and dip to a point about north-west-by-north. The arrows in the diagram indicate the dip of the cleavage planes. See Professor Sedgwick's paper on the structure of large mineral masses, Geol. Trans. 2nd Ser. vol. iii. p. 475.

rallel lines from one end to the other, and inclining at a great angle to a point only a few degrees west of magnetic north." "They appear to me," adds Professor Sedgwick, "only resolvable on the supposition that crystalline or polar forces acted on the whole mass simultaneously in given directions, and with adequate power."

The annexed diagram exhibits a similar instance in the neighbourhood of Ilfracombe in which the contorted



BEDDING AND CLEAVAGE OF DEVONIAN ROCKS IN THE CLIFFS NEAR ILFRACOMBE,

beds of the Devonian slates have been affected by slaty cleavage after the contortions have been produced, the cleavage being perfectly regular through the whole extent of the section. In this instance the bedding, as well as the cleavage, is distinctly marked on the line of the cliffs of the north coast of Devonshire.

Jointed structure is also very commonly met with in slate rocks, and is, as I have already stated, perfectly distinct from cleavage, although the two phenomena have sometimes been mistaken for one another.\* It has been

\* "There is another difficulty in the structure of slate rocks which must be shortly noticed. They are often intersected by a double set of parallel fissures or joints, produced apparently by a contraction of the mass while passing into a solid state. These lines may have been influenced by the crystalline action of the whole mass; for they often divide the rocks on a mountain side into regular prismatic blocks and produce much confusion in the position of the true beds. They do not, however, so affect the inner composition of the rock as to produce persistent laminae parallel to their own planes; and they are not therefore to be confounded with slaty cleavage. Their direction and inclination is variable; but when they nearly coincide with the strike of the beds they may be called *strike-joints*; and when they are nearly transverse to the strike they may be called *dip-joints*." It should also be remarked that in some cases, though rarely, a second cleavage affects the slate rocks and shews a perfection of crystalline arrangement

proved mathematically by Mr. Hopkins,\* that when tabular masses of rock are elevated by a force from below, two sets of tensions act upon the mass, which would naturally produce longitudinal and transverse fractures at right angles to each other, and such fissures sufficiently correspond with certain joints, and cross joints, met with in disturbed districts. In other cases, however, crystalline forces must have acted on a large scale, distinct from those which have produced cleavage, and rather referrible to a peculiar change which takes place in cooling, and which will be explained in the next chapter.† This change, tending in the first place to produce spheroidal concretions, afterwards produces columnar, and ultimately jointed, structure; the one well represented by the regular pillars of basalt characterising the Giant's Causeway and the Isle of Staffa; while the other is exhibited in the blocks, partly cubes and partly rectangular prisms, into which much of the Cornish granite is divided.‡

Whatever the cause may be, and whether owing to

quite equal to that of the original cleavage, although in another direction. These double cleavage planes have also been found associated with the striped and double-jointed structure so common in slate rocks.—Sedgwick's Letters, *ante cit.*, p. 218.

\* Camb. Phil. Trans. vol. vi.

† An extremely interesting instance of the effect of continued heat upon the sand made use of to line the inside of a reverberatory furnace has lately fallen under my own observation, a specimen having been sent to King's College for examination. The sandy floor was originally of perfectly loose texture and of a deep red colour (owing to the presence of oxide of iron). Its thickness amounted to several inches. After having been for about a fortnight at the bottom of the furnace, the part nearest the fire became of a black colour and a loose scoriaceous texture, but at a very little depth the scoriaceous appearance ceased and there was found a considerable thickness of compact, close-grained sandstone without colour, exhibiting a *distinctly columnar structure*. Below this the sandstone gradually passed again into loose red sand as the effect of the heat had been less felt.

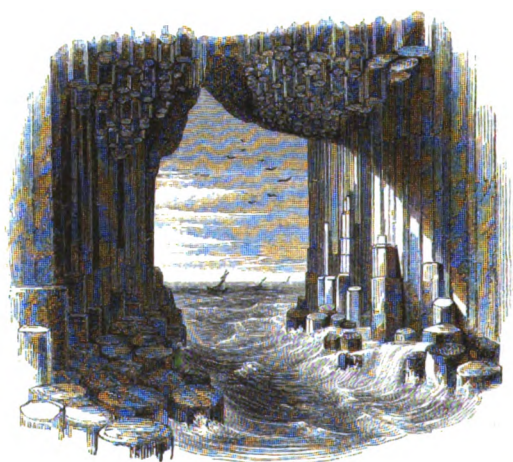
‡ An example of this occurs near the Land's-End, where Sir H. de la Beche describes the granite as bearing a great resemblance in form to a collection of huge basaltic columns.

the action of crystalline and polar forces assisted by heat, or merely due to the long continuance of such action under ordinary temperatures, it is at any rate the case, that these peculiarities of structure are far more commonly observable in the rocks which have been called metamorphic, and in the Plutonic rocks, than in any of those which are fossiliferous as well as stratified; and they are not only more common, but exhibited on a different scale; all the changes being more exactly shewn, and carried out in more minute detail.

I have so frequently had occasion to remark upon the mistaken notions commonly entertained on the subject of slaty structure, that I am unwilling to bring this chapter to a close without once more referring to Professor Sedgwick's valuable paper on the structure of large mineral masses, and directing the attention of Geologists to the importance of attending to his recommendations on the subject of nomenclature. He says, "It would be well to describe no structure as *slaty*, except cases of transverse cleavage; using the term *slate* for a perfect oblique cleavage, and some such term as *flagstone-slate* for imperfect cleavage: and in like manner, *slaty flagstone* may describe a very thin or laminated structure parallel to the stratification." The term *shale* is already in common use for the fissile, argillaceous beds met with in the carboniferous series; and it would add greatly to the definiteness and accuracy of geological language, if these and some other expressions were carefully and generally used in the same sense.

## CHAPTER XLVII.

BASALT AND ITS IDENTITY WITH MODERN LAVA.—ACCOUNT OF  
EXTINCT VOLCANOES AND THE IGNEOUS ROCKS FOUND IN  
THEIR VICINITY.—INTRUSION OF TRAP ROCKS IN ROCKS OF  
VARIOUS GEOLOGICAL PERIODS.



VIEW OF BASALTIC COLUMNS. FINGAL'S CAVE, ISLE OF STAFFA.

BESIDES the disturbances produced by the intrusion of igneous rocks, such as granite &c., which by their underlying the stratified rocks form a natural limit to geological investigations, all the older rocks, and most of those of newer date, have been from time to time subjected to mechanical violence acting from below, and the rents and fissures thus

formed have been partially filled up by melted matter, which in many cases has been forced above the surface, and is spread out in great tabular masses. To these rocks, which are usually called in Geology 'basaltic,' but sometimes also 'trappean,' or 'trap-rocks,' I have already alluded in Chapter XLV., and it is my intention now to give some further account of them ; but in the first place I hope to shew, that as in their mineral structure, and in the manner of their occurrence, they are strictly analogous to the melted lava poured out by modern volcanoes, so also the various appearances they present are analogous, these phenomena being, in fact, merely modifications of a subterraneous igneous action still going on, and whose operations may be traced back by the Geologist to the very earliest periods of the earth's history.

This view of the igneous rocks and of their influence in effecting the elevation and disruption of strata becomes exceedingly important when it is attempted to frame a general theory which shall embrace the whole group of observed facts in Geological Science, for it offers a means of comparing, and sometimes of identifying phenomena, which could scarcely be in any other way obtained.

In describing some of the effects of modern volcanic action\* I have already had occasion to allude to those outbursts of molten rock which often accompany eruptions, and which, rushing on like a torrent of liquid fire, have from time to time proved so destructive. The *lava*, as it is called, thus ejected from the bowels of the earth, first appears in the form of a thick tenacious semi-fluid mass, intensely heated, and, according to the rate of its cooling, it is known to assume many different and singular forms.

\* See *ante*, vol. i. p. 19.



The mineral composition of lava varies considerably in different volcanic districts, but the base is invariably felspar, which is mixed with different proportions of iron and the alkaline earths. The lava often encloses crystals; its structure is vesicular, its internal lustre glistening, and it melts readily into a black glass. Its general appearance as a mineral is, however, greatly dependent on the circumstances of its cooling; for while that part exposed to the air is cellular and full of cracks, and resembling a mass of scoria or loose ashes, the lower part, cooled slowly under pressure, is hard and massive, and so far crystalline as to exhibit a rudely prismatic internal structure.\* So varied, indeed, are the appearances it presents, that the hard tough, massive lava used in volcanic countries for road making, the clear black glassy mineral called *obsidian*,† and the spongy, light, friable *pumice-stone* of commerce, are all but different forms of the same mineral, produced by a difference in the circumstances under which it has cooled.

The mineral called Basalt, which usually occurs in veins and fissures of stratified and other rocks of all ages, and is occasionally also spread over extensive areas, is manifestly of igneous origin, for it has in many cases altered the rocks with which it is in immediate contact, changing limestone into crystalline marble, sandstone into quartz rock, and slate or shale into claystone, and it has often been poured out upon extensive table-lands, filling up all inequalities precisely in the manner in which a torrent of lava spreads

\* The lava from the extinct volcanoes of the Rhine and Central France is beautifully prismatic, and separated into six-sided columns, like those of Staffa and the Giant's Causeway, of which we shall have presently to speak.

† In Europe obsidian (or volcanic glass, as it is sometimes called,) has been formed into reflectors for telescopes; in Mexico and Peru it was formerly made into looking-glasses and knives.

over the country. Its mineral composition strictly resembles that of lava; it has, on the whole, the same general appearance, possesses similar peculiarities of structure, and exhibits very similar differences in external character in those districts where it appears to have been exposed to partial atmospheric action. It only required to transform the one rock into the other in order that the well-known and universally diffused basalt might be identified with the lava erupted from volcanoes in modern times. This, also, has been satisfactorily effected in a very interesting experiment by Mr. Gregory Watt,\* and the actual identity of basalt with modern lava being shewn, there is distinct proof of the former rock having been produced by ancient volcanic action.

The experiment to which I here allude is too important to be passed by without something more than a mere cursory notice. It was made on a mass, weighing seven hundred weight, obtained from a well-known basaltic rock from Rowley, in Staffordshire, and was conducted with the greatest care, and the most minute attention to every change that could be observed to take place during the process.

The mass was placed in a reverberatory furnace, and exposed to the intense heat which is obtained in that way. It was found to melt with a less degree of heat than would have been required by an equal weight of pig iron, and as it melted it was allowed to subside into the deeper part of the furnace in the form of a liquid, but rather tenacious glass. A portion of it being then taken out and suffered to cool, retained the character of perfect glass. The remainder of the mass was left in the furnace, and was cooled very gradually, not being

\* Phil. Trans. for 1804, p. 279, *et seq.*

extracted for eight days. It was then cold externally, but still retained a considerable degree of internal heat. The extreme irregularity of its shape caused it to be so differently affected during the cooling that many peculiarities in the arrangement of bodies passing from a vitreous to a stony state were thus exhibited in a very remarkable way. The most striking of these I proceed to narrate.

The first result,—that of the rapidly cooled basalt resembling obsidian, or volcanic glass, is interesting and important, as it identifies two minerals exceedingly unlike in appearance and texture, and which, indeed, it required this direct evidence to prove identical. The other results obtained from examining the cooled mass are not less important.

The first tendency towards arrangement in the particles of the fluid glass was exhibited in minute globules thickly disseminated through the mass, and where the arrangement extended a little further the mass was observed to be compact, to have an even conchoidal fracture, and it was then of a dark chocolate colour and greasy aspect, and resembled some varieties of jasper in its opacity and compactness.

But if the temperature favourable to the internal arrangement of the particles was continued, as in the thicker portions of the mass, another change commenced, and a still greater advance towards stony texture was observable. This next step took place by a fibrous radiated structure exhibited in connexion with a tendency to spheroidal concretion, the centres of the formation of the spheroids being comparatively remote from each other, and not intermingling when two come in contact, but compressing one another, thus shewing the nature of those conditions under which the columnar structure becomes superimposed; this latter

being clearly only a particular form of the spheroidal structure.

The next change that takes place appears to arise from the fibrous structure of the spheroid becoming compact, so that the internal character of the mass is more decidedly stony, and possesses great tenacity. Its colour is now black, and it is quite opaque, but a continuation of the temperature appeared to render the mass more granular, and its colour more grey, while the molecules arrange themselves into regular forms, the whole mass becomes pervaded by crystalline laminæ, it begins to possess polarity, and the commencement of crystallization is clearly indicated.

The cavities at this point begin to exhibit regular crystals projected from their walls, and this goes on until the mass becomes porphyritic, and ultimately the whole is a congeries of crystals.

The highly instructive and interesting nature of the processes thus traced can hardly be sufficiently estimated until the Geological student has examined for himself the peculiar appearances presented by igneous rocks, and the strict resemblance of many of those which appear most puzzling, with some one or other of the changes thus induced by the different rates of cooling. When, in addition to this, the difference of pressure under which cooling may have taken place is also considered, we shall perceive that there is sufficient cause to account for many extremely complicated phenomena, even without calling in the aid of electricity in a more direct form than is necessarily exhibited in all changes of temperature. We shall also be able to understand the extent and value of the evidence that exists of the comparatively slower rate of cooling in the great masses of Plutonic rock upon which the stratified deposits rest.

The identity of modern lava with ancient basalt, might, however, be almost proved by a continuous chain of evidence arising from a comparison of the matter erupted from recent volcanoes with that found in the neighbourhood of extinct volcanoes of different ages, where true basalt is abundantly present in all the forms it assumes in the rocks of older date supposed to have the same origin. Of modern volcanoes I have already spoken, and it is perhaps hardly necessary to mention that there are a number of cones of volcanic origin in various parts of the world, but in the neighbourhood of existing volcanoes, which have never themselves vomited fire or sulphurous vapours, and which therefore may be considered as extinct, so far as historical evidence can determine.

Since this is the case, it can hardly excite much surprise, especially after what has been narrated of Geological phenomena, that other parts of the earth's surface, far removed from these existing centres of igneous action, should also exhibit similar appearances, and be characterized in like manner by the presence of lava, volcanic ashes, and other volcanic products. Such is indeed the fact, and to a greater extent than is perhaps generally imagined; and as the Tertiary period, when much of the existing land was elevated into its present position, is remarkable for exhibiting several localities where volcanic fires, which have long since become silent, once raged, and whence streams of liquid fire were formerly erupted; so also we shall see, in examining the Secondary, and even the Palæozoic rocks, that similar events occurred, often indeed in those cases beneath the sea, and that throughout all ages similar volcanic agency has aided in modifying the external features of the globe.

The principal and best known points at which volcanic

eruptions have taken place on the continent of Europe, since the commencement of the Tertiary period, from volcanoes which have since become totally extinct, are in the valley of the Rhine, between Andernach and Cologne, in the department of Puy de Dôme in Central France, and on the north-east Coast of Spain, at Olot, in Catalonia. All these have been perfectly quiet, and free from the disturbances of volcanic action, during, and probably long before, the existence of man upon the earth, but all of them exhibit, with the utmost distinctness, series of volcanic phenomena exactly resembling those which are described as characterising Etna and Vesuvius in modern times.

The volcanic district of the Rhine extends for about twenty-four miles from east to west, and from six to ten miles from north to south. The volcanic cones have been forced up through schistose and micaceous beds of the middle and older Palæozoic periods, and the trachytic lava and basalt has been poured out around the base of the hills, often extending to considerable distances without much reference to the present configuration of the country. A number of ancient craters, some of which are now lakes, may be observed at different points on each bank of the Rhine, but the walls of these craters are usually made up of cinders and scoriæ, and the deep indentions and fractures of the walls often shew the points whence a lava current must once have issued. On the whole, however, the lava seems to have been chiefly erupted through cracks and fissures in the subjacent rocks, and to have been spread evenly over the surface, often in very thin bands.

By far the most important feature of the volcanic district of the Rhine, though not that which presents itself most prominently to the passing visitor, is the great extent of the basaltic platform partly in the Duchy of Nassau and

extending on the right bank of the Rhine, but reaching still further to the east, and forming the hills called the Vogels Gebirge. In the former district indeed the basalt is covered up in many places by a remarkable bed of lignite, or brown coal, already alluded to in speaking of the Tertiary formations, but not less than a thousand square miles of country in the neighbourhood of the Rhine have been in former ages overwhelmed by a flood of lava, probably spread out beneath the waters of an inland lake long since dried up. The thickness of the bed is not very considerable.



VOLCANIC DISTRICT OF AUVERGNE, CENTRAL FRANCE.

The district of Central France in former times the seat of subterraneous disturbance, reposes, or rather rises out of a granitic platform; the Mont D'Or, the most conspicuous of the volcanic cones, rising suddenly to the height of several thousand feet, and being composed of layers of scorïæ, pumice stones, and fine detritus, with interposed beds of basalt. A considerable number of minor volcanoes form an irregular ridge on the platform, and extend for about eighteen miles in length and two in breadth. They are usually truncated at the summit, where the crater is often preserved entire, the lava having issued from the base of the hill; and the lavas may often be traced from the crater

to the nearest valley, where they usurp the channel of the river, which in some cases has since excavated a deep ravine through the basalt.\*

In Catalonia the eruptions have burst entirely through Secondary rocks, and the distinct cones and craters are about fourteen in number, but there are besides several points whence lava may have issued. The volcanoes are most of them very entire, and the largest has a crater four hundred and fifty-five feet deep, and about a mile in circumference. The currents of lava are, as usual, of considerable depth in the narrow defiles, but spread out into thin sheets over the plains; the upper part is scoriaceous, further down it is less porous, and at the bottom it becomes prismatic basalt, about five feet thick, resting on the subjacent Secondary rocks.

It is probable that the Western Part of Asia and the Peninsula of India exhibit the phenomena of recently extinct volcanic action on a scale far grander than is known in Europe, for in these countries the lava has been poured out over an area of many thousand square miles, and rests in flat tabular masses upon the country. The volcanoes of Asia Minor are still in a state of disquiet, and the elevation of the Chain of the Caucasus has doubtless been continued to within a very recent period; while so closely does the past approach the present in this part of the world and in America, that it is often difficult to decide to which period many of the phenomena must be referred, and it has happened even in Europe that volcanoes, supposed to be extinct, have once more burst forth, and apparently with tenfold violence, after a long period of repose.†

\* Lyell's Principles of Geol. third edit. vol. iv. p. 139.

† This was the case with Vesuvius, not known to be a burning mountain before the great eruption during which Pompeii was entombed.



The coast of Antrim, presenting the magnificent basaltic columns of the Giant's Causeway and the adjacent district in Ireland, has long been celebrated as exhibiting very remarkable instances of the protrusion of large quantities of molten rock in former times. In this part of Ireland, indeed, there are many hundred square miles of country, extending from the neighbourhood of Belfast to Coleraine, in which a considerable series of rocks of the Secondary period, terminating with the chalk, have been covered in this way. On the coast, especially towards the north, the basalt is seen capping the chalk, which is usually much altered and hardened into limestone, and the flints are reddened and burnt near the contact. In other places, clayey or shaley beds, are changed into hard siliceous rock, and sometimes indicate crystalline structure; while in others, again, as at Ben Evenagh and elsewhere, the basalt assumes a character of extreme grandeur, and successive stages of ponderous and shapeless masses rise to the base of the steep basaltic summit, and there break into pinnacles and precipitous cliffs.\*

But, in the interior of the country, the protruded rock, although present, sinks to a low level, and along the western shores of Lough Neagh and Lough Beg is so much concealed, as to appear only in isolated lumps or small ridges, rising here and there above the surface. In many places, indeed, it is evident that the softer parts of the rock have been carried away, and that the whole of the detached portions were formerly continuous; and this is not to be wondered at, when we consider that the mineral composition and relative hardness is very variable, and that the whole district has been exposed to diluvial action, and to the denuding force of running water.

\* Portlock's Geol. Report of Londonderry, &c. p. 103.

It is not easy to account for the occurrence of these large masses of igneous rock in the north-east of Ireland, or to connect them with any focus or centre of eruption. They have probably been forced through wide cracks formed in the subjacent strata, and thus belong to the class of phenomena sometimes considered separately from the tabular basalt, and denominated trap veins, and dykes. But however this may be, all the true characters of lava are apparent in the rock under consideration, and all the strata discovered in contact with the basalt have been altered by heat. Phenomena almost exactly similar are seen in the Island of Staffa, and in some others of the Western Islands of Scotland; and the picturesque beauty of Fingal's Cave and the Giant's Causeway have been too often described to render any account of them necessary in this place.

In England, and apparently throughout a considerable part of the continent of Europe, there is very little appearance of igneous rock erupted in a melted state during the formation of the strata of the Secondary period. Traces of such phenomena have, indeed, been observed, but they are comparatively few; and, for the most part, the Secondary period seems to have been one of quiet deposition and little change or disturbance, at least in European latitudes.

But in the rocks of the Palæozoic period such appearances are far more frequent, and they very commonly affect the whole, or nearly the whole, of the rocks of that period, without interfering with the overlying New red sandstone,—shewing the probability that an interval must have elapsed after the deposition of the Palæozoic rocks, during which subterranean disturbances were going on, and thus adding to the number of the indications of such

an interval having existed, afforded by the organic remains of the two groups of formations.

Basalt occurs in the older rocks in two conditions, which may be separately considered ; namely, 1st, in the condition of an overlying mass, or of beds alternating with the regular strata ; and 2nd, as dykes, traversing stratified and other rocks and filling up cracks and fissures. In this latter state it often forms the connecting link between the tabular masses and some great subterranean reservoir, although, in other cases, it does not rise above the surface of the rocks which it penetrates. Its mineral constituents are essentially the same as those of modern lava, but occasionally hornblende predominates, when, from the peculiar colour of that mineral, the name of greenstone is applied to the variety. The most usual characters of the basaltic rocks of England are (1) their iron-grey colour, approaching to black ; (2) their frequent tenacity and hardness (whence their value in making roads) ; and (3) a sharp and sometimes conchoidal fracture, and a granular aspect, indicating the commencement of crystalline structure. They are very liable to superficial decomposition, in which case the colour changes to a rusty brown, owing to the oxidation of the contained iron, and the decomposition sometimes penetrates a considerable depth into the mass of the rocks, exhibiting spheroidal masses less decomposable than the rest of the rock.

There are several beds and overlying masses of trap among the carboniferous rocks of England, and many others which have only penetrated the Silurian rocks, and which, therefore, must have been erupted anterior to the deposition of the Newer Palæozoic strata. It will be sufficient to allude shortly to the principal instances, in order to give a general idea of the nature of these rocks of intrusion in our own country.

Basalt occurs in overlying masses in many parts of the North of England, eminences of this kind having often been chosen for the sites of feudal castles; and at Bamborough, one of these castles, the thickness of the mass has been ascertained, by boring for water, to be seventy-five feet.

A remarkable instance of overlying basalt may be observed forming a group of hills near the town of Dudley, in Staffordshire. The rock here has received the name of *Rowley rag*,\* from the village of Rowley, situated on one of the highest of the basaltic hills. It is extremely hard, and of coarse texture, and has been used for paving the streets of Birmingham: a similar rock is found at a distance, forming the upper part of the lofty hills of Titterstone Clee and Brown Clee in Shropshire. The trap in these places distinctly reposes on the coal measures, and where it comes in contact with the coal has greatly injured its quality, and reduced it to a sooty state.

The *toadstone* of Derbyshire is a well-known rock, apparently interstratified with the rocks of the carboniferous period in that county, and it offers a very striking example of bedded trap. This toadstone, which had generally been described as repeated in three distinct beds, has been supposed by Mr. Hopkins to be the effect of only one or at the most two eruptions of melted rock, and he has endeavoured to shew that the several beds, apparently distinct, merely consist of the original one repeated in different parts of the district by faults. The abundance and accuracy of the detailed information offered in support of this view, render it difficult to doubt that the conclusion is correct. The determination of this

\* It was a mass of this rock which formed the subject of Mr. G. Watts' experiments, already described.

point is of much importance in a country so valuable for its mineral resources, and the more so, because the identification of the limestones and associated lead veins, depends on the position of the interstratified volcanic rock.\*

Basaltic dykes traverse the carboniferous limestone in many parts of the north of England, some of them being as much as from thirty to forty feet in width. These dykes are either vertical or very highly inclined, and the basalt of which they are formed is of a greenish-black colour and coarse texture. Sufficient evidence is afforded of their igneous origin, and of the rock having been injected in a melted state, by the altered appearance of the wall of the dyke; for the adjacent coal, in one example at Walker in the Newcastle coal-field, is actually converted into coke, which on one side was found to be in some places eighteen feet thick, and on the opposite side upwards of nine feet:† but this fact of the coal being completely charred and turned into coke is common throughout the district whenever a basaltic vein traverses coal bearing strata.‡

\* At Teesdale in Yorkshire, and elsewhere in the north of England, there are instances of highly picturesque scenery owing to the presence of basaltic rocks in various crystalline conditions. In these cases the associated limestones are usually altered and converted into marble.

† Conybeare and Phillips' *Geol. of England and Wales*, p. 447.

‡ A still more remarkable instance than that in the text, of the alteration effected in the neighbourhood of a trap-dyke, is related in the *Transactions of the Northumberland Natural History Society*, vol. ii. p. 343. An account is there given of the greenstone dyke on Cockfield-Fell and its effect on the coal strata in one of the collieries of the great north-eastern coal-field. In working the coal towards this dyke, the change was observable at a distance of fifty yards, the coal becoming dull, and losing its quality for producing flame. Nearer the dyke it has the appearance of half-burnt cinder, and still nearer consisted of sooty matter caked together, while close to the dyke the bed was reduced in thickness from six feet to nine inches. This dyke is nearly vertical, it has been traced about seventy miles from S.E. to N.W. and is in some places eighteen yards in width,

The rocks of Volcanic origin which are most commonly associated with basalt are those called *trachytic*, or *trachytes*, from their rough feel when rubbed between the fingers. Trachyte is sometimes considered to bear the same relation to granite that lava does to the ancient basalts, and is composed chiefly of felspar, combined frequently with a considerable proportion of silex. It abounds in the volcanic district of the Rhine, and there forms a kind of imperfect building stone, and it is also common in various forms in the Puy de Dôme, where it appears under very similar circumstances.

Besides the ordinary form of trachyte as a volcanic rock it appears yet more frequently in pulverulent masses of pumice, forming what is called *tufa*, which has been found in rocks of all ages interstratified with fossiliferous beds but itself rarely containing organic remains. The presence of this tufa invariably marks the vicinity of igneous and erupted rocks, and in this way it is often useful to the Geologist, more especially in the older formations.\*

It has frequently been attempted, more especially by the Continental Geologists, to class the various rocks of igneous origin with reference to their predominant minerals, but these arrangements have never attained any very general acceptance in our own country.

and it is calculated to have spoiled as much as one hundred yards of coal along all that part of the seam traversed by the dyke throughout Cockfield-Fell.

\* The pumice of commerce can hardly be regarded as a distinct mineral as it is only a cellular and filamentous state which several volcanic rocks (chiefly trachytes) are capable of assuming. It is not met with in all volcanic districts and seems to be erupted only under peculiar circumstances. Vast quantities have been quarried at the foot of Cotopaxi, one of the celebrated volcanoes of the Andes, and it there occurs in beds distinctly stratified and is often associated with obsidian. The principal localities in Europe in which it abounds are the Lipari Islands, and some of the islands of the Grecian Archipelago; Iceland, and the extinct volcanic district of the Rhine. It is also found in Teneriffe and in some of the volcanic islands of the Eastern Archipelago.

There appear to be two series,—those in which felspar or hornblende respectively abound,—in rocks of each geological period, and these in their most characteristic forms of granite or trachyte and basalt or lava are sufficiently distinct, but they pass insensibly into one another by innumerable variations which demonstrate the similarity of origin of all the unstratified rocks.\*

It may therefore be considered on the whole, that the occurrence of trappean rocks is a geological event belonging to all successive periods, and affecting all rocks, whether stratified or not; and it is also evident that, while no rocks bear more strictly the marks of igneous origin than those called basaltic, even they are sometimes so distinctly stratified as to have formed thin layers, alternating with fossiliferous strata of aqueous origin, and probably erupted from volcanic vents opening at the bottom of the ocean, as we have reason to believe happens occasionally still. There is, therefore, in these phenomena—which, it must be repeated, connect the rocks of known igneous origin such as are still from time to time erupted, with the most ancient of those rocks supposed to be Plutonic—a still further and more interesting point rendered clear, the change being even indicated by which the regularly stratified fossiliferous rocks pass first of all into metamorphic, and then into distinctly igneous formations.

\* Phillips' Treatise on Geology, vol. ii. p. 54.

## CHAPTER XLVIII.

EFFECT OF DISTURBING FORCES IN PRODUCING THE PHYSICAL FEATURES OF THE GLOBE.—GENERAL CONSIDERATIONS CONCERNING DESCRIPTIVE GEOLOGY, AND THE CONCLUSIONS TO WHICH IT LEADS.



VIEW OF THE WETTERHORN—ÖSERLAND ALPS.

I HAVE now nearly brought to a conclusion the account which I proposed to give of Descriptive Geology, and it remains only in the present chapter to recapitulate, shortly, the main facts that have been recorded, and re-arrange them in such a form as to give a distinct view of the results which the study of Descriptive Geology has really attained.



In order to do this in the most satisfactory way, I think it will be advisable that I should state as briefly as possible the bearing of the one class of Geological phenomena upon the other, and shew how the two great antagonist forces of water and fire have both assisted in the great work of preparing the earth, during its successive mutations, for the inhabitants who have from time to time dwelt upon it; and as I have hitherto carefully avoided entering into the discussion of theoretical views, a consideration of which was indeed quite inconsistent with my original plan, so here I shall confine myself simply to a comparison of results, the main facts on which these results are founded having been already placed before the reader in the preceding chapters.

The joint action of aqueous and igneous forces in modifying the crust of the earth, (each of these forces being sometimes conservative, and both occasionally destructive,) is a fact too obvious to require any proof, but still, on the whole, it is not difficult to understand in what sense aqueous and atmospheric agents are the preserving and restoring powers, while fire modifies and destroys. It is not, however, altogether in this way that I mean to consider them, in my endeavour to explain to the reader the nature of their mutual influence.

Without discussing at any length the subject of earthquakes, or offering any arguments to prove that the cause of such disturbances and of the changes of level accompanying them must have been of the same kind as that which effected the elevation of islands or continents and the formation of mountain chains, I think it must be clear, both from what has been already said and from the nature of the case, that since the former bed of the ocean has been in many cases elevated, and become dry land, constituting even the tops of mountains, and that in the neigh-

bourhood where this change of position has taken place there is usually abundant evidence of the existence of plutonic rocks, whose eruption must have been accompanied by great mechanical violence, there was at least some intimate relation between the two series of phenomena. Taking the case of our own island, let us illustrate the subject by a comparison of its physical geography with its geological structure.

In the first place, England, situated towards the north-west of the continent of Europe, repeats within its small comparative area almost the whole Geological sequence as shewn upon the continent, and the beds, although locally disturbed, may be said to dip on the whole towards the east or south-east, a direction perfectly accordant also with the general inclination of the beds, as exhibited on the adjacent shores.

In the next place we may observe, that although it is the newer beds which are most nearly continuous, in those parts where the channel which divides England from the continent is narrowest, the older rocks on the north-eastern and south-western extremities of our island correspond also to those of the opposite coasts of Norway and Brittany. We may observe too, that the main elevations in our island are, for the most part, in the general direction of the strike of the beds, and that those which are apparently most nearly connected with the general Geology of the country are in the western counties, the others being chiefly local or accidental. This is evident from the direction of the drainage, and may readily be observed by consulting the map. What then is the conclusion to which we must arrive by a consideration, even of this superficial kind, of the structure of a country with which we are familiar? It cannot be doubted that the physical features are not only

modified, but were originally produced with reference to Geological structure, and that in most cases the circumstances of the elevation of the beds are not only those to which we must look in endeavouring to make out the first generalisation—the prevailing dip and strike, but that the Physical Geography of the country is also due to their agency.

But again, if we look a little more narrowly we shall find that, with scarcely more than one or two exceptions, the igneous and altered rocks of England form the line of greatest elevation in the country, running nearly parallel to the general strike, and that even the apparent exceptions, when examined, strengthen the conclusions to which we should otherwise arrive.\*

It appears, therefore, evident that the general outline of the land was sketched out beneath the surface of the sea long before the rocks were deposited of which a great part of England is composed, and that a distinct direction was given at a very early period to the elevatory forces. Hence we may suppose has resulted the physical aspect by which our island is now characterised, and the original direction seems to have been communicated by the protrusion of igneous rocks, not often reaching the surface, but sufficiently near, and acting for a sufficient time, to alter to a very great extent the older mechanical rocks in contact with them. The direction once given in this way, a line of least resistance would necessarily be formed, and the great subterranean forces have rarely succeeded in materially changing it, and never to a sufficient extent to produce a lasting effect. I may observe,

\* The occurrence of several bosses of granitic rock in Charnwood Forest, in Leicestershire, and in the range of the Malvern Hills, between Worcestershire and Herefordshire, are the chief of these apparent exceptions. They are both interesting, and in each case the period of eruption was anterior to the new red sandstone, which is deposited in horizontal layers around the bases of hills composed of granitic and metamorphic rocks.

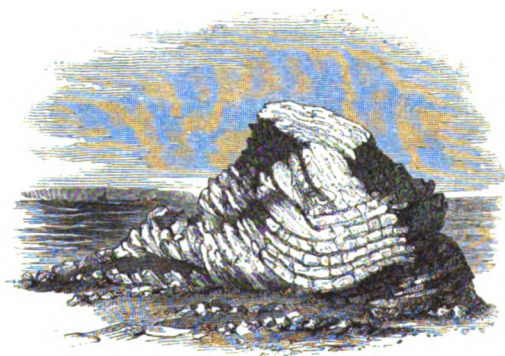
that even at this day there is every reason to believe that minute changes of elevation are still going on in the same direction along our western coasts; and it is impossible not to connect this fact, proved by the existence of raised beaches and submarine forests at various points along the coast, with the occasional disturbances and slight shocks of earthquakes that have been felt from time to time both in those parts of England and in Scotland.

That the deposition of the different strata, described in detail in the preceding chapters, occupied a vast period of time, I think I have distinctly proved in my account of their mineral composition and the number and condition of their fossils; and yet more, in the details of those revolutions and successive creations that have taken place so frequently, and yet so gradually, both in the animal and vegetable world.

But it would appear that there have also been other revolutions and disturbances less gradual, and which have also affected the surface of the land to a very remarkable extent. I allude not only to the disturbances accompanied by the protrusion of igneous rocks, already referred to, but others which we only recognise by the results affecting strata which we have every reason to suppose were deposited horizontally.

One of the chief of these is exhibited in the south-west of England, in the Wealden district, and offers a remarkable instance of local disturbance, not interfering with the general structure of the whole country, but, by a happy accident as it were, unveiling to the eye of the Geologist a local deposit scarcely traceable in other parts of the known world, and, at the same time, offering to the mathematician a problem of the most interesting kind, and one not a little valuable, as bearing on the mode of action of the

subterraneous disturbing forces.\* With this remarkable exception, however, (which is distinctly proved to be posterior to the chalk by the fact, that the whole of the cretaceous system rests with perfect conformability upon the Wealden beds,) there is no evidence of any considerable displacement of the rocks of the Secondary period in England. The mere fact of the elevation of the Weald, and the complete dispersal of the chalk, which must once have covered the whole district, is sufficient proof of the magnitude of the causes that were in action between the close of the Secondary and the commencement of the Tertiary period ; and they indicate the length of time that must have elapsed before the deposition of those lower beds of the London Clay, which offer so little mark of having been formed by the degradation of the chalk upon which they repose.



CURVED STRATA OF CARBONIFEROUS LIMESTONE. STACKPOLE ROCKS,  
NEAR TENBY.

\* Here again I forbear to enter on the speculations that have been offered to explain the elevation of the weald, and can only allude, in passing, to the valuable investigations of Mr. Hopkins with reference to this subject. They belong to that department of Geology into which I do not enter, not wishing to mingle the discussions that must arise when seeking for causes, with descriptions of phenomena which are simple statements of matters of fact.

The nature also of the effects thus produced on some of the older rocks are exhibited in the instance represented by the vignette in the preceding page, which represents the contortions of a bed of carboniferous limestone near Tenby, on the South Welsh coast, in the direction of the axis of disturbance.\*

In contemplating wide breaks such as these in the Geological sequence, there seems a natural tendency in the mind to assume some great and unusual cause and some total revolution in the physical constitution of the world as the only means of satisfactorily accounting for them. But however natural such a feeling may be, it is certainly not supported by evidence, nor is it absolutely needed to account in a probable way for the fact.

It is very possible, for instance, to imagine that an extensive tract of land may once have existed in the middle of one of the great oceans, either in the northern or southern hemisphere. A large proportion of the bed of that ocean may have been, since the establishment of the present relative conditions of land and water, in a state of nearly perfect repose, so far as regards the accumulation of new deposits containing fossil remains, or, at least, such deposits, whatever they are, might easily have been carried away by denudation at the first emergence of this ocean bed at a future day. Such a condition also may have gone on for ages, and during the time when changes were gradually taking place in the other part of the earth's surface, no succession of phenomena might be there indicated. It is not difficult to suppose, that in some such way the interval between the Secondary and Tertiary period may be ex-

\* The vignette at the commencement of this chapter, representing the outline of one of the high mountains of the Alpine chain, and that at the end which represents contortions of strata in the Venetian Alps, offer other examples of the same fact in two distant points on the Continent of Europe.

plained without having recourse to the idea of a sudden and total destruction of all species of animals and vegetables upon the globe, and a re-creation of similar species immediately, to attain similar ends.

But the circumstances of the existing land, even at a very late epoch of the Tertiary period, is a subject yet more difficult to make out than its condition at the time of the deposition of the earliest beds of that formation. There is, indeed, hardly any problem in Geology that has not been explained in a more satisfactory way, or by theories presenting fewer improbabilities and contradictions than this: namely, the condition of Northern Europe at the time when those great heaps of gravel and rolled fragments of rock, which we now find among the superficial deposits, were strewed upon its surface. The nature of the mechanical force by which they were conveyed has yet to be explained and in order to account for this phenomena some Geologists, as I have already stated, have imagined a great wave rushing over the surface with irresistible violence, and returning again and again loaded with fragments it had torn up in its violent course; others have thought it sufficient to suppose that the sea conveyed icebergs, each of them bearing on its surface many tons weight of stones and gravel obtained from the shores of the Polar seas, and that these gradually melting, deposited their burden at the bottom of the sea: while others, again, have seen evidence to convince them that, in times so nearly recent, huge glaciers descended into the valleys and covered hundreds of miles of country, extending down from the various mountain chains in Northern Europe; and that these glaciers, slowly creeping on, bore along with them the gravel, in such moraines as at this day mark the progress of similar, although less gigantic, frozen masses.

Such are some of the speculations that have been offered on this difficult subject. It is, perhaps, not too much to say, that all of them fail in accounting satisfactorily for the observed phenomena; and that many more observations must be made before we can hope to cross the wide and dark gulph which separates the past from the present.

But if this, and some other points in Geology, are still confessedly difficult, and not yet clearly made out, it does not, therefore, follow, that the science itself is weak and uncertain, or that what has been shewn by independent observation in other things is the less valuable, or to be depended on with diminished confidence. Professor Sedgwick has well observed with reference to such fears, that "this view of Geology, considered by some as a sign of its imperfection, is in truth, a part of its glory. Many of its conclusions are as firmly fixed as the truths of demonstration; but the boundaries of its conquests are still undefined. We profess to build only on observation and experiment, but there are many wide provinces in Geology still unexplored, many that are known imperfectly, and in no part of her realms are her subjects bound by such unyielding fetters as to leave no room for the mind's creative powers." \*

The study of Geology has, I trust, now been shewn to offer phenomena of the highest and most complicated interest both to the philosophical naturalist and to the mathematician. On the one hand, it has enabled us to discover the existence of a succession of mineral deposits, endless in number, infinitely varied in their lithological character, and of a total thickness almost incalculable, but certainly amounting to many thousand fathoms; and these contain an equally varied succession of organic

\* Letters, &c. *ante cit.* p. 243.



remains, not less remarkable for their number and the state of perfection in which they are handed down, than for the indications they offer of an order of succession amongst organised beings, totally unlike the uniformity that exists in inorganic matter.

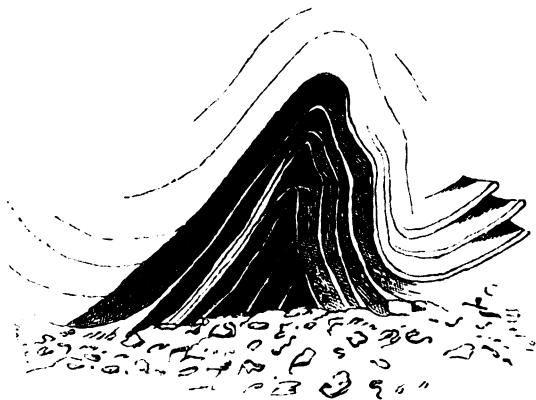
On the other hand, these beds, regularly deposited, and evenly spread out at the bottom of the sea, retaining, as they often do, the most delicate and fragile shells and other substances that have sunk down after the death or destruction of the animal to which they once belonged, have since then been exposed to the action of forces acting from below. They have thus been sometimes elevated *en masse* above the level of the sea, and are still horizontal as they were first deposited,—at other times, they have been exposed to ruder shocks, and overwhelming masses of melted matter have forced their way through fissures and rents in their solid substance, or have been spread out evenly upon their surface. They have also been exposed to the action of subterranean forces of other kinds, and these have lifted them high into the air, so that mountains which pierce the clouds are formed out of those stratified fossiliferous rocks which were originally mud and sand washed into the sea by some great river, or which were elaborated by the silent but effectual labour of the coral animalcule, or by the accumulated skeletons of myriads of minute animals scarcely visible to our unassisted sight.

And the great problems suggested by the observation of these phenomena, the one class relating to the course of nature in her ever-varying modes of distributing life and organisation, and the other to the action of those laws which, so far as we know, are unchangeable, and according to which particles of matter act upon one another, are offered by the Geologist to the Natural Philosopher,

with every assistance that can be derived from observation and experiment. In investigations of this kind, the experiments are those which Nature herself has performed, and the observations, if sufficiently numerous and accurate, supply all the details of the experiment. Whatever be the state of Geological theory, and however that may be affected by future observation, such changes cannot interfere with the results already attained. There is much to expect, much to hope for, and much that we would willingly learn, but which is, in all probability, beyond the powers of man to accomplish in Geology. The knowledge at present acquired concerning the earth's history is incomplete, and we cannot, with reason, expect that it shall ever be otherwise; but our knowledge of that history is of a kind upon which we can depend, for it is derived from observation and not theory,—it is not the mere opinion of speculative men, but the actual laying down, in their proper order, those truths, of whose existence we are distinctly made aware. There is a succession of deposits, such as has been described in the foregoing chapters,—there have been successive creations of animals and vegetables, such as I have there endeavoured to picture to the reader;—there have been, also, successive disturbances and disruptions, the strata being sometimes elevated, and always altered more or less in position; and all these things have happened according to the regular course of Nature. If we are not to believe what is plainly set before us, and if we may not deduce those conclusions which the simple examination and comparison of facts suggests to our minds, we cannot reasonably believe anything, and, indeed, the strongest foundations of our belief must be shaken and destroyed.

Descriptive Geology therefore, viewed as a branch of

Natural History, will be seen to possess a reality and an importance entitling it to respect both as a narrative of facts and as a science of observation. I trust to shew in the subsequent chapters of this Work that it is also sufficiently advanced and possesses sufficient stability and certainty to afford important assistance to the practical man, and that therefore it ought to form an element in the education of all those who would either familiarise themselves with the works of Nature or avail themselves of those works for the benefit of their fellow men.



CURVED STRATA OF LIMESTONE. VENETIAN ALPS.

## PART THE THIRD.

## PRACTICAL GEOLOGY.

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CHAPTER I.

THE PRACTICAL APPLICATIONS OF GEOLOGY, AND THE ADVANTAGES  
TO BE ANTICIPATED FROM AN ACCURATE GEOLOGICAL SURVEY  
WITH REFERENCE TO THIS SUBJECT.

I UNDERSTAND by the expression ‘practical application of science,’ an account of the different methods by which the various facts of the science, as discovered by actual observation, and the general laws which have been deduced from a careful study of the true value and analogies of those facts, may be shewn to bear upon the pursuits of practical men, assisting them in coming to right and useful conclusions in their ordinary business. I hope to be able to shew that the facts of Geology already recorded, and the general conclusions arrived at, may be thus made use of in the ordinary affairs of life, and applied immediately to practical purposes. That such an attempt, if successful, will be highly useful, no one can deny ; and I trust that the errors and imperfections which may be observed in the attempt, will also be useful, as pointing out to those who may follow in the same path, how to effect a still greater amount of good.

But while I am thus desirous of so treating the subject of Geology as to render it useful to practical men,

I would anxiously guard myself from being understood as only valuing the pursuit of science in proportion as it is thus *immediately* applicable to practical results. I look upon scientific research as being in itself a most beneficial and useful employment, and chiefly so when undertaken without regard to any other result than the elucidation of truth, and the establishment of general laws; and I am sure that really valuable conclusions are far more likely to be deduced, when Geology, or any other science, is studied for its own sake, and the conclusions are incidental, than when the only object is to derive some immediate benefit by empirical investigations. I say this, because I wish the reader to understand that I am not, in the common acceptance of the word, an *utilitarian* philosopher, and also because I wish to express my firm conviction that the advantages to be derived from the pursuit of science are only to be expected when there is a clear and definite plan laid down, according to which the information to be acquired and adapted may be arranged in order, and in its proper place.

It can hardly be necessary to bring forward any proof in illustration of the fact, that much, not only of the physical condition of a country, but even of the habits and peculiarities of the civilized people who are its inhabitants, may be very greatly, if not mainly, dependent on its Geological condition. As exemplifying this, we may suppose, for instance, an intelligent traveller—a perfect stranger to the political and economical condition of England—to land on the south-western coast of Cornwall, and after travelling through that county, cross to Swansea, and proceed through Wales, thence by the mining district of Lancashire to Durham, and so through Northumberland to Newcastle-on-Tyne. His natural con-

clusion might be, that the country was naked and savage, the people rude and uncultivated, living, for the greater part of their time, underground, and obtaining a precarious subsistence by mining. If the same traveller should, however, re-traverse our island, returning to the south-western coast by way of York, Nottingham, and Stafford, through Worcestershire, and thence by Bristol, and through the east of Devonshire, he would find the country a rich, highly cultivated garden, the people employed in agriculture, the land fertile, and the whole character of the scenery changed. So, also, he might pass through a manufacturing district, by Wiltshire, Oxfordshire, and Warwickshire, into Yorkshire, and arrive at a third, and very different conclusion, as to the general resources of the country and the habits of the people. In all these cases he would have been travelling on the *strike* of the beds of the different geological periods, as they are brought to the surface in England, and the uniformity, as well as the peculiarities observed, would be entirely due to the existence of certain Geological conditions. A single glance at a Geological map will, indeed, at once give an idea of the general structure of a country, of the relative value of different districts for special economical purposes, and of the advantages that may be expected to result from various engineering operations.

If such is the practical information derived by the Geologist from the study of a district, of which the Geological features have been already laid down, he is, in a similar way, able to acquire some notion of its Geological structure, from the contemplation of the physical geography of a tract of country. A line of hills, for instance, rising gradually from one side, and presenting a steep face on the other, is an almost certain indication of the line of

strike of a stratum, or series of strata, the dip being in the direction of the gradual inclination. In extensive plains, the surfaces have often been denuded of the softer rocks, as clay and sand; while bristling hills and peaks mark the protrusion of the igneous and volcanic rocks; and the direction of the drainage indicates, in a way not to be misunderstood, the out-crop of various strata, the great lines of fracture, and the direction, and often, also, the relative intensity of subterraneous disturbances, all other marks of whose former existence have long since passed away.

And the information with regard to the structure of a country thus derived, is by no means confined to the particular facts that have been actually observed. It is in the highest degree probable, that the prevailing strike, once discovered, will be found constant over a large tract, with the exception of local irregularities the existence of which is often marked on the surface. The general direction of the drainage once made out, streams may be looked for, in places where their existence could not be otherwise guessed at; and the chance of success in any undertaking that may be commenced will be greatly increased by this preliminary knowledge of the elementary facts of the Geology of the country.

The importance of an acquaintance with Geology to persons engaged in mining operations of all kinds, is so obvious, that for a long time Geology was looked upon as a branch of Mineralogy. The position of the two sciences is now, indeed, reversed; but the relation between them continues to be of the highest and most vital interest to the latter, — an interest which must increase rather than diminish, as the structure of the earth is more completely understood, and as the laws, according to

which the particles of rocks have re-arranged themselves, shall be deduced from the consideration of phenomena, chiefly brought to light by Geological investigations.

The application of Geology to mining must ever be the first, and the most deeply interesting of all branches of Practical Geology, and it involves many points exceedingly abstruse, and at present very ill understood.

The nature of mineral veins, and the circumstances under which they have been filled, (one class containing minerals not metallic, and another the metallic ores); the general direction of productive veins in particular districts; and the whole train of mechanical, chemical, and electrical causes that are assumed to have acted in producing these phenomena, are all intimately connected with the structure of the rocks in which the veins occur; and as they are found in rocks of all ages, the Geologist is not at liberty to neglect them, or to leave them out of sight, in speculating on the value of any theory he may frame.

The subject of mineral veins is, however, a kind of neutral ground, occupied either by the Geologist or the Mineralogist, although strictly belonging to the former. It is the link uniting the three departments of *descriptive*, *theoretic*, and *practical* Geology; but it is no easy task to give a distinct notion of so difficult and complicated a subject, nor, in spite of the importance of the subject to the practical miner, has it hitherto received from the Geologist, the full investigation it well deserves.\*

\* The metalliferous deposits of Cornwall and Devon, perhaps the most important in England, have been lately described by Mr. Henwood in a volume of the Cornish Geological Transactions (vol. v. 1843), and they had previously been the object of careful investigation by the scientific men employed in the Ordnance Geological Survey, the results of which were published in the "Report on Cornwall, Devon, and West Somerset," by Sir H. De la Beche. The mining districts on the Continent are well described in very great detail in several works.



What is called by the French the '*Exploitation des Mines*,' or the nature of the mechanical contrivances which are brought into action, and the methods of underground working which are undertaken, in order to detach ore from the rock or vein in which it is bedded, and prepare it for the Metallurgist, belongs, also, in some measure, to Practical Geology, and will, in its turn, be a subject of description, and I shall also dwell upon another, and less frequently described branch of mining operations, that branch, I mean, which involves the application of mining principles to miscellaneous purposes, and the methods employed in obtaining the mineral produce which is deposited in beds, and not distributed in veins. In England, and to English interests, the extraction of coal (the most important of these) is a subject of paramount importance, but a really practical and accurate description of the methods employed for that purpose hardly exists in our language.\* I shall, therefore, dwell at some little length on the working of coal mines, the ventilation of the works, and the accidents to which they are subject.

But mining, in all its branches, is only one department of Practical Geology, for in all operations of Agriculture, of Engineering, and of Architecture, the earth and the different rocks of which its crust is composed, are the materials upon which, and by means of which, every work is to be accomplished. I shall endeavour to shew how, and to

\* It is singular that in this respect the French should have preceded us, and that the best, if not the only accurate and complete Work of even one of our coal-fields, should be in a foreign language. I allude to the memoir by M. Piot, in the first volume of the *Annales des Mines* for 1842. The papers by the late Mr. Buddle, chiefly in the Transactions of the Northumberland Natural History Society, are extremely valuable, but offer no complete and connected view of the subject. A work was, indeed, published some years ago, entitled "Fossil Fuel," but this work, although it contains some useful matter, I can hardly recommend as giving such an account as was required of the subject.

what extent, the persons engaged in such pursuits may be benefitted by a general knowledge of Geology, and how far our science ought to enter as a necessary element into the education of every practical man, whatever may be the department in which he may have to labour.

To render Geology an effectual aid in engineering and agriculture, as well as to teach that kind of Geological surveying which can alone be valuable in practice, it is necessary, in the first place, that I should recur to a subject already alluded to, and explain fully the nature of those illustrations which offer the means of registering Geological information, giving an account of those more perfect maps and sections of a country, which, while they are the result of very considerable knowledge, tend to enlarge and apply that knowledge in the greatest possible degree.

And if, indeed, as has been said in a former chapter, the ordinary Geological maps, which exhibit a general outline of the structure of a country, are useful and necessary in illustrating such descriptions as may be sufficient for preliminary instruction in Descriptive Geology, the more perfect and minute investigation involved in a Geological survey is not less useful or less necessary in the department we are now about to consider, that of Practical Geology. I proceed, therefore, to describe, as briefly as possible, the nature of this work, and the extent to which it is at present carried on in our own country.

There will, I imagine, be few of my readers who are not aware that the formation of a general map of the British Islands, prepared from a very careful and complete trigonometrical survey, under the superintendence of the Board of Ordnance, was undertaken several years ago, and has been steadily advancing towards completion. The greater part of England, the whole of Ireland, and a part of Scotland,

has already been surveyed for this purpose, and a considerable number of sheets of the map have been long before the public.

When the general map of England and Ireland had advanced some way towards completion, strong representations were made to Government, pointing out the great advantage that would be derived from a Geological survey, to be carried on also under the superintendence of the Board of Ordnance, and the object of which should be the formation of a Geological map and sections of the country, in as perfect a manner as was possible, and the accumulation of all kinds of Geological information that might be obtainable in the course of the survey. The representations thus made were ultimately acted on, and Mr. (now Sir Henry) De la Beche was appointed Director of the Geological survey. The work commenced with the south-western counties of England, and the counties of Cornwall and Devonshire and part of the adjacent county of Somersetshire were finally coloured, and the sections and detailed information published, in the year 1839. Since then a portion of South Wales has been similarly surveyed, and the maps of this district are now nearly ready for publication.

It may be sufficient to say of them that they represent, with the utmost fidelity, every geological fact that the united and careful observation of a large number of experienced and clever Geologists could detect.\*

An account of the system pursued in the Geological survey will be a sufficient explanation at once of the objects

\* There is, indeed, but one thing to be desired with respect to these maps, and as the attention of Government has been directed to the work, it is greatly to be hoped that it may soon be supplied. I allude to the laying down on the maps a system of what are called 'contour lines;' by which is meant lines of equal altitude above a certain standard level. With these lines marked, a glance at the map is almost sufficient to determine the direction that should be taken in draining, road-making, and other important economical operations.

of the survey, and of the nature of the first great operation in Practical Geology, and I cannot hope to offer a better account of this system than was given by Sir Henry De la Beche before the Commissioners lately appointed by Government, to inquire into the facts relating to the Ordnance Memoir of Ireland. Being asked to describe the system pursued in the prosecution of the English Geological survey, he says,\* “I receive the order of the Master-General of the Board of Ordnance to investigate a certain district, and I then proceed myself to look at that district on the large scale; having done so, I select the Assistant-geologists that may appear most proper to undertake the examination of portions of that district. Having those minor districts assigned to them, they proceed in their labours, I from time to time visiting them, and checking up those labours. Our mode of operation is this:—we receive maps from the proper officer at the office in Southampton; having received these maps, we proceed on the ground, and actually survey in all the boundaries of the geological lines, so that the lines are as true as the roads upon the map. This being done, we proceed to make the necessary sections, which are constructed in the first place to shew the occurrence of the beds above each other, on a scale of 40 feet to the inch; every detail is followed, and at the same time that we investigate the mineral structure of those various beds, we carefully examine into the organic remains which each may contain. Having thus got a view of the general superposition of the beds, we next proceed to make sections in different directions, such as may best afford a general view of the country, or rather of its Geological structure; and this is done upon a scale of six inches to the mile, the height and distance being on the same scale. With regard

\* Report, &c. with Minutes of Evidence. Question 99, p. 8. Lond. 1844.

to the maps, in the first place the examinations in the field by the Assistant-geologists and myself having been properly verified, the lines that were obtained are laid down upon what is technically called a dry proof, namely, an impression of the sheet taken on dry paper, in order that the engravers may trace off, rub down, and subsequently engrave those lines. You will observe that all the coal crops (in the maps of South Wales) are laid down throughout the sheet, and that every boundary line is also distinguished. This proof having been engraved, the map is then coloured, and all the geological detail, as far as colour is concerned, is given in the finished map."

It was then asked whether the labours of the Geological survey were considered to be directed with reference to the progress of British Geology, both strictly as a science on the one hand, and bearing on the application of that science to the useful purposes of life on the other, and an answer being given that it certainly was so, Sir Henry was requested to describe the useful purposes of Geology.

He said, "It is directly applicable to mining, agriculture, and building purposes, especially with reference to durability of materials, and the mode of obtaining them; and I should think that these three would afford a general view of the subject. There are others, but they are minor. I should say that, with reference to the sheet I have had the honour of shewing you, (a part of the Geological map of South Wales,) the agricultural character of that district was directly as the colours laid down upon it, and that, therefore, a person with that sheet before him, might rely upon the agricultural character of the property he might possess in those various areas. With regard to mining, I would wish to call attention to those lines that have been technically called contour lines; because I should

say that, having such lines, knowing the dip of the various beds of rock or coal, and being aware of the faults in a coal district, you have the means of knowing exactly beneath any portion of the ground the distance between the surface of that ground, and the vein or bed of coal which you wish to get at, which is most important. Considered with reference to all matters of draining or pumping the water out of mines, a system of contour lines is most important, not only in the coal district, but in many of the metal-mine districts of the country."

These subjects embrace the whole of the Geological survey, which may, indeed, be considered as an examination of Great Britain so far as regards the science of Geology and its application to the useful purposes of life ; including mineral substances as applicable to arts and manufactures ; agriculture as connected with Geology ; and giving an account of the applications that have been already made, besides suggesting others that may hereafter be derived from the arrangement of rocks and the Geological circumstances of the district under consideration.

I have been induced to give this account of the Geological survey at considerable length, because I am satisfied that it offers by far the most important and efficacious means for the general application of Geology that can possibly be devised, and I am anxious that the reader should understand that it does so chiefly from its accuracy, which is as nearly perfect as can be obtained by the best instruments in the hands of the most efficient and experienced observers. With this map, and the information associated with it, the miner, the agriculturist, and the engineer, may at once make the applications which I shall describe in the following chapters ; and where the map is not to be obtained, something like the same method must be adopted

by the practical Geologist to obtain imperfectly the same kind of information.

But the formation of a Geological map and sections, and the publication of the materials accumulated in the course of the survey, is not the only result that has been attained. Owing to the active exertions and the representations of the present Director of the survey, (Sir H. De la Beche,) the numerous opportunities, afforded during the actual prosecution of the out-door work, of collecting specimens illustrative of the application of Geology to the useful purposes of life, were directed to be taken advantage of, and the collections thus made have been placed in a room provided for them under the care of the Board of Works. In this way the 'Museum of Economic Geology' was established, and a large store of materials has already been accumulated and arranged in a manner admirably adapted to illustrate the most useful practical applications of Geology.\* The Museum was originally intended to contain specimens of rocks, shewing the Geological character of each district with reference to agriculture as well as to mines and buildings; to comprise also specimens of the ores of the various metals employed for useful purposes, so as to exhibit not only the mode of occurrence of these ores in veins, but also to explain the several processes by which they are fitted for the market, and the metals extracted from them; and, finally, models to shew the different methods of extracting and raising the ores and minerals from mines, and their application to the useful and fine arts.

\* Of this Museum, which is at present contained in two houses in Craig's Court, Charing Cross, an admirable account has been published by Mr. Sopwith (some of whose beautiful models may be seen in the establishment), and to this I would refer every one who wishes to become acquainted with the contents of the Museum, and the great extent to which its objects have been already carried out. I am greatly indebted to this little Work of Mr. Sopwith's for the account I have given above of the contents of the Museum.

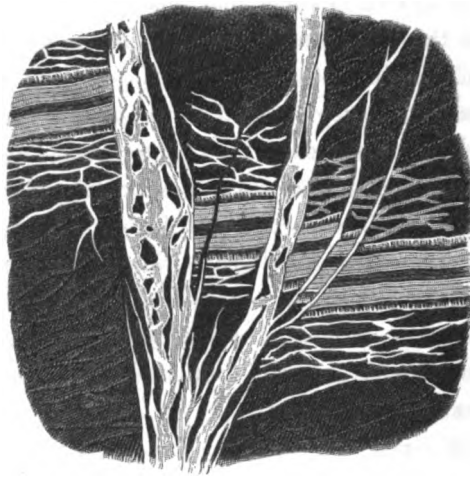
In addition to these objects, and soon after the Museum was first established, a department was added for the reception of mining records, (an object of the very highest importance,) offering, for the first time in this country, a safe and public receptacle for documents which may hereafter be of the greatest value, and the want of the preservation of which has often been the cause of severe accidents and great losses.

The Museum of Economic Geology is, therefore, a public acknowledgment of the importance of Geology as a practical science, and at the same time it must do more than almost any other thing that could have been devised to increase this importance by placing the practical results immediately before the world. No one can visit the Museum without being satisfied of the great value of such an institution as a source of useful information, and it will, I trust, be soon felt, that no one is fit to undertake the superintendence of any great work in mining, engineering, architecture, or even agriculture, without some considerable knowledge of Geology; a knowledge not confined to the heaping together of facts, but extending to principles; a knowledge, therefore, which is not empirical and superficial, but sound and philosophical.



## CHAPTER II.

ON THE NATURE OF MINING GENERALLY, AND THE DIFFERENT KINDS OF MINING OPERATIONS. — THE NATURE OF MINERAL VEINS.



VEINS CROSSING ONE ANOTHER.  
NEUBHÖFFNUNGSFLACHEN MINE, NEAR FREYBERG, IN SAXONY.

*One twenty-fourth the natural size.*

CONSIDERING the practical application of Geology as included under the three heads of Mining, Engineering, and Agriculture, it will be most convenient to speak of each of these in its turn; and since mining is that of which the relations to Geology are most evident, it presents it-

self naturally the first in order. It is needless to enlarge on the importance of Geological knowledge to every one who has the direction of mining property.

There are, however, two very distinct kinds of mining operations, dependent on the manner in which the mineral produce is distributed in the earth; for it may either occur in cracks and fissures, which have been produced in various rocks by mechanical violence subsequent to their deposition; or it may, on the other hand, be regularly stratified, and alternate with beds which form a portion of the solid framework of the globe. According to the circumstances under which it occurs in veins, extremely different methods must be pursued, in order to extract it from the bowels of the earth, and bring it to the surface; and some kinds of mineral produce also are immediately available for practical purposes when brought out of the mine, while others require much preparation.

It is thus the case that various processes are employed in different parts of the country, the mining operations in the one having little or no resemblance to those in the other, so that something more is required to give an idea of these operations than merely to visit and become familiar with the methods adopted in any particular district.

The fundamental difference that obtains in these various operations has reference very much to the manner in which the mineral to be extracted was originally deposited, for on this principally depends the method to be adopted in extracting it from the mine. In Cornwall, where are the chief mines of tin and copper in England, and in North Wales and some other districts, where copper is also obtained, the metallic ore is extracted from irregular cracks in the strata, (usually of the middle or

newer Palæozoic period,) or from similar fissures in the igneous rocks which there reach the surface. These cracks, or fissures, filled up with some mineral substances, are called 'mineral veins:'—they will be found to present some remarkable peculiarities in the order of their arrangement, and in the nature of their contents, and they differ essentially and entirely from those beds or strata which supply the coal and iron ore in South Wales and Staffordshire, and the coal in the Newcastle and Durham coal districts, although similar veins containing rich iron ore exist in other parts of England, but are only worked to mix with the poorer ores, which are far more abundant.\*

But the mineral veins of Cornwall differ, also, considerably from other mineral veins containing lead and zinc ore in Derbyshire, and thus it becomes important to define strictly the peculiar and characteristic marks of these masses of metallic ore, and the circumstances under which we may expect to find them. I propose, therefore, in the present chapter, to consider the subject of mineral veins, omitting all allusion to minerals which are found regularly bedded, and which alternate with, and form part of, the series of the fossiliferous stratified rocks. In order to do this satisfactorily, I must first define what is meant by 'a mineral vein,' when the expression is technically employed in Geology.

Veins have been defined by Werner to be "mineral

\* In all the principal iron mines on the Continent the ore occurs in veins which are often of extraordinary richness and extent. The celebrated mines of Dalecarlia, and others, in Sweden, whence the iron is obtained for the manufacture of the best steel, and several iron mines in Prussia, Nassau, and elsewhere, are very remarkable for the great magnitude of the lumps of rich ore which are found in them. Many of these mines have been worked for centuries, and are still productive; but they have never supplied iron so cheaply as the poorer ores of England, the vicinity and abundance of the coal and limestone by means of which the metal is reduced more than counterbalancing the difference in the richness of the produce.

repositories of a flat or tabular shape, which traverse strata without regard to the stratification, having the appearance of rents formed in the rocks, and afterwards filled up by mineral matter, which differs more or less from the rocks themselves." The form of a vein, as it appears in a vertical section, may be understood from the vignette at the head of this chapter, and I have annexed a plan, also accurately drawn, which exhibits the line of intersection of a vein with the surface.



GROUND PLAN OF SPLIT VEINS. HUEL FORTUNE MINE, CORNWALL.

*Scale, one inch to a mile.*

*l. l.* The main lode, or vein.      *d. d.* Cross courses.  
*e, e', e''.* Elvan courses, or dykes of igneous rock.

Veins differ from dykes rather in their contents, than in the form and nature of their bounding walls. Both are fissures in rocks filled with mineral matter subsequently to the existence of the fissure as an open crack; but when such fissures are filled with trappean, or other igneous rocks, or with felspar in any shape, injected, apparently, in a state of fusion, they are called dykes; while, when they are associated with metalliferous ores, or contain crystalline minerals, they receive the name of veins. Veins, therefore, are commonly filled with copper, lead, tin, or other metals, in combination with sulphur, oxygen, carbonic acid, &c. associated with the salts of lime and barytes, and with argillaceous matter and quartz, but

it must be understood that the presence of metallic ore is not absolutely essential.

The fissures which have thus become, or which contain veins, pass, although not indifferently, through all the rocks met with in their downward descent, and though, in a few instances, there has appeared to be a termination of some, which are small and unimportant, all large veins continue beyond the reach of the deepest mine. They vary greatly in horizontal extent, and are usually lost sight of by passing into narrow cracks not worth the miner's notice. Their breadth is infinitely irregular; and a vein, whose average width is three or four feet, will sometimes be not more than an inch or two across, but at the distance of a few fathoms will have a breadth of eight or ten feet.\*

There have been several names given to mineral veins, according to local peculiarities that have been observed in their shapes, and the arrangement of their contents. Thus the terms *pipe* and *shoot* have been applied to cases in which the metallic contents of a vein have been segregated into portions, inclined at various angles in different veins, but nearly parallel in the same vein; and in a long vein these portions usually mark a series of parallel spaces more metalliferous than the rest. The latter term, "shoot," is commonly used in certain districts

\* The largest and thickest vein known to be worked is the celebrated *Veta Madre* mine, near Guanajuato, in Mexico. This vein, from which there were extracted nearly four millions of pounds' weight (troy) of silver in the first ten years of the present century, varies in width from twenty-five to fifty yards; it is worked to the depth of one hundred and eighty fathoms (upwards of one thousand feet), and has been followed horizontally for upwards of six English miles.—Humb. Pol. Ess. Transl. vol. iii. p. 135.

As a contrast to this, and an instance of very minute veins that are yet found worth working, I may mention a number of lodes in a tin mine at Limousin varying from half an inch to a little more than one inch in thickness.

where the masses of ore, occurring in stratified (generally metamorphic) rocks, take an oblique direction in the veins, and become conformable to the dip of the beds. When the direction of the vein itself is nearly parallel with that of the beds, and the ore makes no such shoots in a lode, it is called a "pipe-vein." Mr. Henwood has observed, that, "in the case of shoots, these portions of the vein generally dip from neighbouring granite, and that this is the case, whether the rock which contains the vein be itself sedimentary or crystalline." \*

Veins not unfrequently expand against particular layers of rock, constituting what are called in some mining districts "flats," or lateral extensions parallel to the stratification.

Another variety in the appearance of veins, is that in which, by successive nearly parallel fissures, all filled with mineral matter, a vein becomes of very great and almost indefinite width, bewildering the miner, and often preventing him from being able to understand or follow so capricious an arrangement. Such a condition of the vein is called by the German miners a *Stockwerk* (no doubt from the necessity of working in successive floors, or stories).† It not unfrequently happens, that in masses of this kind, portions of the neighbouring rocks appear to be enveloped in the mass of the veins; and it is usual for small *strings*, as they are called, to pass off from the ore to the rocks which form the sides of the vein. Occasionally, also, these strings are more important, becoming

\* It should be understood that Mr. Henwood's observations chiefly apply to Cornwall.

† Masses of iron ore are among the most remarkable of these stockworks, some in Piedmont exhibiting a thickness of upwards of three hundred and fifty yards, and others in Sweden extending almost half a mile, with a thickness of several hundred yards.

rich when the vein itself is poor; and it is a notion with the Cornish miners, that such appendages have an influence on the productiveness of the vein.

Veins usually occur in a position nearly vertical. In the north of England, their inclination from the vertical rarely amounts to more than  $10^{\circ}$ ; in Cornwall it averages much more than this, but is seldom known to exceed  $45^{\circ}$ , and in the foreign mining districts it is usually inconsiderable.

The walls, or sides, of a vein, are often harder or softer than the adjacent rock, having been affected by mineral impregnation.\*

There are several mining terms that will necessarily be introduced in the following pages, and with these it is desirable that the reader should be familiarly acquainted. I will now as briefly as possible explain them.

In the first place, the rocks in mining districts, whatever their character may be, are usually spoken of as the *country*; the veins containing the metallic ores are *lodes*; and those not metalliferous *cross courses*; the dip or inclination of the vein to the horizon is called its *underlie*, *hade*, or *slope*; and the intersection of the vein with the surface, (the strike,) determines what is called its *direction*.

Considering veins as tabular masses of ore, enclosed between parallel planes, that which forms the superior of the two at any spot, is called the roof, and the inferior the floor, but both are sometimes (when the underlie is small) denominated *walls*. I have already explained that *strings* are small branches from the vein, and may be looked upon as minute filaments into which the vein sometimes splits;

\* "In the vicinity of the *lodes* (veins) and strings, the rocks not only alter in their mineral characters, but almost invariably become softer, possibly from the action of water, which the cellular character of the lodes allows to circulate more freely than it does in the rocks."—Henwood, Cornish Geol. Trans. vol. v. p. 188.

and these when very small, are occasionally called *threads*. Other terms that it will be found convenient to use, will be explained as we advance. I proceed now to speak of the contents of veins, and the manner in which those contents are arranged.

The mineral substances, and metallic ores, which fill up metalliferous veins, rarely have any relation with, or dependance on, the rocks containing the veins. We may also consider that they form of themselves two distinct classes of phenomena; the mass of the contents being usually either siliceous, fluorspar, or carbonate of lime, all in a crystalline state, and together forming what is called the *veinstone*, and the substance we call *ore*, which contains in some form or other the metallic produce. This latter it is the object of the miner to extract, and he only regards the rest in proportion as it enables him to judge with greater or less certainty of the abundance or absence of the ore.

But mineral substances in which no trace of metallic ore is found, or which do not contain it in sufficient proportion to be worth extracting, much more frequently fill the veins, and are greatly more abundant than the others, and it becomes necessary for the Geologist to observe them accurately if he wishes to arrive at any knowledge of the general laws which have influenced the filling of the veins; for this knowledge can only be arrived at by carefully studying all the facts on record with reference to the nature of their contents, and the uniformity of direction that characterises each kind, (those namely which are productive and those which are unproductive of metallic ore,) in the same district.

It is rare that veins containing crystalline quartz, fluorspar, or carbonate of lime, are entirely without metallic ore in some form, and the ore then usually occurs either in



small veins within the principal one, or in grains or crystalline masses, and disseminated crystals. Other veins, however, in which the veinstone is earthy or powdery, are very rich in ore, while those which are altogether sterile are generally filled with sandstone or clay, or with broken fragments of the adjacent rocks.

The distribution of ores in the vein is exceedingly irregular, and the relation which exists between the various circumstances of magnitude, extent, or inclination of the beds is not in the smallest degree known. Many isolated facts have, indeed, been recorded on this subject, but so contradictory do these facts appear, that no satisfactory general theory has yet been deduced from them.

A change of thickness appears to have great, but variable influence on the metalliferous contents of a vein; and where the vein swells out and bifurcates in such a way that the sum of the thickness of the bifurcations is greater than that of the vein, there is said to be very generally not only an increased quantity, but an improved quality of ore.\*

In many veins the nature both of the veinstone and the ore, is observed to be different at different depths, but it is not at all the case that the vein becomes richer as we follow it in the deeper sinkings. Veins, however, are manifestly changed whenever the containing walls change from sedimentary to crystalline, and even the mechanical condition of the walls of the vein has sometimes exercised an important influence on the contents.

In Cornwall there often appears to be a certain degree of

\* This is the case in the Veta-Grande in Mexico, a vein worked by twenty-one mines, and on a line nearly a mile and a half long. The richest portion in the whole of this great extent is also the thickest, where the vein attains a thickness of more than ten yards. On the other hand, where it is nipped in, and becomes not more than from three to four feet wide, it is comparatively poor, and hardly worth working.

order in the arrangement of the metallic ore in the veins ; but, however this may be, it seems an almost universal law that a change of rock is characterised by an instant alteration in both the metalliferous and earthy minerals of the lodes, and this, not only in passing from one rock to another of different mineral composition, but even when the containing rock is altered only in hardness and texture. So commonly is this the case that the intelligent miner looks to such appearances with greater anxiety than even to the vein itself, and they are considered by him among the most certain indications upon which he can venture to confide.

In the older rocks, and especially in Cornwall, a vein, productive of copper ore in slaty ground, and entering granite without any change of direction or break of continuity, becomes, perhaps, at first richer, and furnishes ores differently mineralised, but if pursued far into the granite it is almost always observed to become poor.\* When, however, a productive vein crosses an elvan or granitic dyke, the ore sometimes becomes rich and abundant, but sometimes vanishes altogether. It is worthy of remark, that the granite of Kit Hill, and of Dartmoor, have hitherto, with a single exception, yielded tin ore only, whilst the slate series of that district contains ores of copper, lead, and silver, but scarcely any tin.

In the lead mines of Derbyshire, which traverse alternating bands of carboniferous limestone and the erupted rock called toadstone, the veins which are thick and valuable in the limestone are nipped in, and become valueless when passing through the trap. In the mining district of Als-

\* It is considered in Cornwall that the productive copper mines are always upon the junction of granite and killas ; in other words, that the veins are only valuable where there is a change of country.

ton Moor again, where cracks and fissures in the stratified rocks contain the productive veins of lead, although the same fissure is common to a very considerable number of alternations of limestone, carbonaceous shales, and gritty sandstone, the lead ore is never found abundantly except in one bed of limestone. From this bed (about twenty-three yards thick) four-fifths of the whole metallic produce of the district is obtained, the remainder being distributed among eight other limestones, eighteen gritstones, and twenty-eight beds of shale, having a total thickness of 260 yards.

It appears, indeed, that nothing can be more variable and unaccountable than the relation of the metallic ores in a mineral vein to the circumstances of position of the vein, but that in spite of this there exists throughout a certain amount of order, and an approach to regularity. In all districts, traversed by mineral veins, there are, for instance, what may be called systems of veins, each system being characterised by some peculiarities of position or contents, and each, so far as we can judge, referrible to a distinct period. In Cornwall there have been described eight such systems, and the same number had been observed by Werner, at Freyberg. It will be right to allude shortly to the nature of these.

In Cornwall the first class of veins are those which appear to have been the earliest formed, and they form a very large majority of the whole number in the district. They are the older tin veins; they underlie to the north, and are traversed by those of the second class, which are comparatively few in number and of small importance.

These two classes include all the lodes from which tin ore is extracted; their width varies from a mere string to

as much as thirty-six feet, and most of those which are productive range east and west.

The third class of Cornish veins are the east and west copper lodes, and these form the greater number of all the copper lodes in the county; they always cut across the tin lodes when the two kinds meet, and they are usually accompanied by small veins of clay.

The fourth class consist of what are called the *contra* copper lodes, and are few in number; their direction is N.W. and S.E., or at right angles to those bearings.

The fifth class includes the cross courses, which run N. and S. or nearly so, and contain no tin or copper, though sometimes a little lead ore: their underlie is various; they are tolerably wide, and have been traced on the surface to considerable distances.

The remaining three classes are of comparatively small importance to the miner, but they are valuable as adding to the number of facts on the subject of mineral veins. One of them includes the recent copper ores, and another the corresponding cross courses, while the last includes the *slides*, (composed wholly of slimy clay,) and consisting of a number of narrow imperfect veins, rapidly underlying, and running in all directions.

In almost every case the productive veins run east and west, and the cross courses north and south, and the more recently filled fissures and partings are composed almost wholly of clay, so that, as a general rule, veins which contain a greater quantity of this clay traverse those which contain a smaller quantity of that substance.

The systems of veins in the Freyberg districts are described by Werner, and offer a series of facts somewhat analogous to those observed in Cornwall, but the metals are different, and so also are the prevailing directions of the

lodes. The first, and most ancient, are chiefly north and south, and include those veins from which the chief supplies of lead and silver have been obtained. The second system (*contra-lodes*) are more argentiferous, but much thinner. Their direction is about north-east and south-west.

The veins of the third system are all north and south, and those of the fourth at right angles to them, being what are called in Cornwall cross courses. They both contain lead glance. The others are less important.

In the English lead districts, the systems of veins are much more simple than in Cornwall or Saxony; the direction of the productive veins is, almost without exception, east and west, and they are traversed by cross courses, not productive, at right angles to them. The underlie is seldom considerable, and it is tolerably uniform throughout the district.

On the whole, and viewed with reference to the whole district, the direction of the productive veins in Cornwall is also strikingly uniform, and the mean of nearly three hundred observations, recorded by Mr. Henwood, gives  $4^{\circ}$  S. of W.,\* while the actual direction in nearly two-thirds of the number, differs but little from the average.

\* Cornish Geol. Trans. vol. v. p. 250. The actual number of observations tabulated is 295; of this number the direction in 182 instances was between W. and S.W., and in 62 others between W. and N.W. Dividing Cornwall into ten districts, the mean direction of the veins in seven of the districts is much more south of west than the general mean, as the other three districts chiefly contain the *contra lodes*.

The volume from which this and some other notes are taken, is entirely filled with an elaborate account, by Mr. Henwood, of the Metalliferous deposits of Cornwall and Devon; and this account, taken in connexion with Sir H. De la Beche's Report of the Geological Survey, leaves little to be desired with regard to the economic Geology of mining in this interesting district. Mr. Henwood's Work contains an enormous mass of detail with regard to all the principal matters connected with mining, and must form an admirable text book for the mining student and the practical miner.

Besides the productive veins or lodes, all mining districts are traversed by other veins, usually at right-angles to the former or nearly so, but which are rarely metalliferous; or which, if they are so, contain some kinds of ore not abundant in the lodes. The principal minerals in these *cross courses* are quartz and clay, the quartz being usually crystalline. In Cornwall it has been found that out of one hundred and sixty-three cross veins, whose directions were taken, one hundred and eighteen bear between north and north-west.\*

Having thus described the chief phenomena that have been observed with reference to the appearance of mineral veins themselves, it remains only to consider their relations with one another, and the circumstances under which they may have become a part of the rocks now containing them; and I shall endeavour to shew, in the first place, by such evidence as I can bring before the reader in a few pages, that veins must in almost every case be of more recent origin than the rocks which contain them. I have already, in speaking of the different systems of veins, assumed that they were not all of the same age, and I shall also, before concluding the present chapter, offer such proof of this as will, I think, be satisfactory.

Werner long ago attempted to prove, by a number of arguments, the truth of these important facts. He shewed the probability that cracks and fissures which may hereafter become mineral veins have ever been, and are still forming, and he directed attention to the fragments of adjacent rocks often found in veins, as a proof that the filling up of the veins must have been subsequent to the consolidation of the rock. But he also asserted, from observation, the important and unanswerable fact that veins intersect

\* Loc. cit. p. 259.

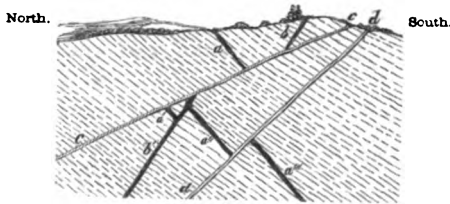
one another; a vein of newer origin often displacing an older one, breaking its walls, and altering its texture and contents at the place of contact. A more modern fissure also often extends through the adjoining rock into an older one, and the two veins join, and run parallel for a short distance, while sometimes a new fissure is permanently stopped, coming in contact with the tough walls of a former vein.

The vignette, at the commencement of the present chapter, is an instance of the intersection of veins, and can only be rationally explained by supposing that the intersection which has taken place was accompanied by a slip or fault which has produced the shifts observed in the older vein.

The relation which veins bear to the rocks or beds in which they occur, and the nature of their internal structure, composed of different kinds of minerals, also seems to indicate very clearly that every fissure, and therefore also, *à fortiori*, the filling up of the fissure, is more recent than the formation and consolidation of the rocks, and it will even appear that we may often determine the general direction of veins in a district, by observing that of the disturbing forces, and the directions they have taken. The relation that exists between these disturbing forces and the fissures in the rocks being thus made evident, there can no longer be any doubt of the fact that veins are of posterior origin to the rocks they traverse. Werner concludes his argument thus, "Wherever I have seen veins of considerable size crossing each other, I have always found that they had been formed at different periods. For when two veins of different directions and inclinations meet, one of them always intersects the other, and this in its turn may be traversed by a third, and so on. In this way we see that the first rent had been filled before it was traversed by a

second, and that this, in like manner, was filled before a third was formed."

As an instance of singular complication arising from the intersection of veins in faulty ground, I subjoin a vertical section from one of the Cornish mines, in which it is not easy to see at first the nature of the disturbances that have



VERTICAL SECTION OF INTERSECTING VEINS. HUEL PEEVOR MINE, CORNWALL.

*a, a', a''*. Tin vein.

*b, b'*. Copper vein.

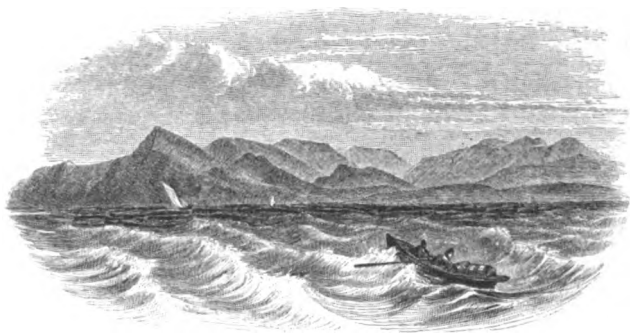
*c, d*. Faults, or slides.

produced such an effect. A little consideration, however, will shew that the tin vein (*a*) has been first displaced by the intersection of the copper vein (*b*) accompanied by an upheaval to the south. Afterwards, the displaced vein of tin, and the vein of copper have both been affected by the fault (*c*) which has carried them downwards to the north, and lastly, the fault (*d*) has again heaved a portion of (*a*) upwards to the south. The ground plan of these disturbances is exceedingly complicated.

On the whole, then, it may be concluded as probable, from the nature of the case, and as completely borne out by the facts recorded, first, that mineral veins are of various ages and quite independent of the age of the rock in which they occur; secondly, that the fissures which now form mineral veins have not been filled up without some reference to the nature of the rocks in which they are contained, and that the filling up was therefore, in all probability, sub-



sequent to the formation of the fissure; and, thirdly, that the fissures which contain metalliferous ore are chiefly in certain definite directions, constant in the same locality for the great majority of instances, but that these are crossed nearly at right angles by another set which are unproductive. We shall see, in the next chapter, how far this direction of productive and unproductive veins has reference to the general structure of a country, and how far it may be supposed to be due to forces acting through very extensive districts.



VIEW OF CROAGH PATRICK.

## CHAPTER III.

ON THE DISTRIBUTION OF MINERAL VEINS AND THE EXPLANATIONS THAT HAVE BEEN OFFERED TO ACCOUNT FOR THE PRINCIPAL FACTS CONCERNING THEM.



MINING DISTRICT. VALE OF GLENDA LOUGH.  
COUNTY WICKLOW, IRELAND.

THE different metals and metallic ores are not found mingled at hazard with the various rocks of which the earth's crust is made up, nor are the mineral veins of which we have been speaking in the last chapter indifferently distributed in all parts of the globe, without reference to the nature of the rock that may predominate. So far is this from being the case, that we find many extensive districts utterly without any trace of mineral riches, while others again are abundantly sup-

plied; and these differences are not unmarked by Geographical as well as Geological phenomena, concerning both of which it is necessary that I should now give some account.

It will be obvious to any one acquainted with the various districts celebrated for their mineral riches, that while, almost without exception, those districts are remarkable for their hilly and even mountainous character, so, on the other hand, the widely extended plains of Europe, Asia, and America are either entirely deprived of such sources of wealth, or possess them very sparingly. These facts with regard to the Geographical distribution of metalliferous veins are not a little remarkable, and they become more interesting when considered with reference to the Geological structure of the same districts.

Our own island occupies the first place among all the countries of Europe, and even exceeds them all in respect of its mineral riches. Cornwall, Derbyshire, and Cumberland, are the three mining centres in England, and each of these districts is also remarkable for its mountain character.

Cornwall furnishes all the tin, and seven-eighths of the copper produced in England.\* The undulating barren surface of this county, its granitic axis rising at different points to the height of from 1000 to nearly 1300 feet above the sea-level; the abundance of Devonian schist (or *killas*) and mica slate, and the great granitic dykes called *elvans*, which penetrate the mechanical rocks, all mark the district as unfit for the ordinary operations of agriculture, and in that respect poor and barren; but although the landscape is desolate, this very sterility often indicates a surface which covers mineral treasures, and the

\* The Isle of Anglesea, and some other districts in North Wales, supply nearly all the remaining copper ore. It is needless to remark, that these localities offer no exception to the generalisation offered in the text.

bare granitic bosses become the scenes of mining operations, scarcely anywhere exceeded in practical value.

The other districts in the British Isles most remarkable for their mineral riches, differ, of course, in some points of detail from Cornwall and Devonshire. In Derbyshire ores of lead are extracted from the hilly country of the neighbourhood of the Peak, so well known, and so often visited for its picturesque beauty. In Northumberland, Durham, and Cumberland a wide extent of high moorland is intersected by the valleys through which run the Tyne, the Wear, and the Tees, and many branches which feed these rivers; and the deep fissures forming these valleys lay open to view numerous veins of ore (chiefly of lead, like those of Derbyshire,) and direct the operations of the miner to the places where it is sufficiently abundant to reward his toil.\* The elevated tracts of Wicklow, (a view of which is represented in the vignette at the commencement of this chapter,) Wexford, and other parts of Ireland, the hilly

\* The picturesque features of a country are so nearly associated with, and so dependant on, its points of Geological interest, that I think it will not be out of place to allude here to some of the beautiful and interesting scenery in the north of England characterising the district from which a considerable portion of the lead used in England is obtained. I select the Northumberland and Durham district, because I believe it is much less visited by the tourist than Derbyshire or Wales.

The lead-mines of the north of England are chiefly worked in the vicinity of Alston Moor, where the three counties of Northumberland, Durham, and Cumberland meet together, and from the lofty and bold hills of which the three rivers, the Tyne, the Wear, and the Tees, take their origin. Of the valleys through which these rivers run, Weardale is perhaps the most beautiful, but Teesdale the most romantic.

Both sides of Weardale, for some distance along its lower part, present the richest vegetation and great rural beauty. The soil is fertile, the crops abundant, and much woodland is interspersed, but the patches of trees become rarer as we ascend the valley, and towards its upper part the trees are solitary, until we rise to the wild, treeless, heath-covered hollow in the mountain, which forms the head of the dale.

The river Tees rises in a hollow at the foot of Cross Fell, and flows for many miles through a desolate valley, with a little grass land on each side, and here and

country of Flintshire, and other parts of North Wales, and some of the mountain districts of Scotland, are also well known, and have been worked to advantage for their mineral produce.

In France there are five districts in which metalliferous ores are found, and in each case they occur in schists of a very ancient Geological period, which have been much fractured and disturbed by the subsequent intrusion of igneous rock. The first of these districts is that of Brittany, which greatly resembles Cornwall in its Geological structure, and also, though on a smaller scale, in its Geographical configuration, and which contains ores of tin and argentiferous ores of lead.

The mining district of the Vosges is the most promising among all those that have been hitherto worked in France, and contains some veins of great value, from which ore has been extracted from time immemorial. The argentiferous ore of lead, occurring in veins both numerous and extensive, forms the principal source of mineral produce, and although at present it is not worked, it offers every prospect of success to the adventurer. The veins traverse gneiss, and they form two systems nearly at right-angles to each other, the north and south system being the most productive, but the cross courses also containing several metallic ores. A considerable number of valuable ores of iron are found in this district.

there a solitary tree. At a most romantic spot in the upper part of Teesdale the river dashes over a precipice of sixty-nine feet, and further down in the valley there are a number of exceedingly beautiful spots embosomed in wood, with the Tees flowing on the south side, and the hills receding to a considerable distance.

The town of Alston, the mining centre of the district, is beautifully situated close to the river Tyne. The valley of the Tyne below the town is richly cultivated, and for about five miles above it ascends, between lofty hills, to where the river rises, in a hollow, at the foot of Cross Fell; this picturesque mountain giving a character of considerable grandeur to the surrounding scenery.

See Appendix to First Report of Mining Commissioners, part ii. p. 721.

The great platform of Central France forms a third centre of mineral riches, and the chief produce, as in the Vosges, consists of an argentiferous ore of lead contained in veins traversing the mica schist with great uniformity in a north and south direction. Besides this ore of lead an ore of antimony (chiefly the sulphuret) is abundantly distributed through some of the veins, but these are of no great thickness, and occur near the contact of the gneiss and mica slate, which wrap round the granitic centre, and are therefore in the vicinity of igneous rock. Ores of copper, manganese, galena, blende, and an oxide of chrome are also found distributed through some of the veins of this district.

The chain of the Pyrenees is not without indications of mineral wealth, consisting chiefly of ores of iron contained in a white saccharine altered limestone of the secondary period, which is associated with schistose clay. Mines of copper and argentiferous lead ore have been formerly worked, but are now abandoned.

The fifth, and last mining district of France, occurs in the French Alps, where, near Grenoble, some small veins have been worked containing iron ore and native gold.\* Other mines of lead and iron have been formerly worked, but are now neglected.

Spain has long been celebrated for its extensive and valuable mines of quicksilver and lead. The former metal is obtained chiefly from Almaden, in the province of La Manche, from mines which have been open since the time of the Romans. Cinnabar is the principal ore, and it occurs in veins from 30 to 40 feet thick, extending in an east and west direction for more than a mile. The lead is said to

\* This mine was feebly worked during part of the last century, but not to profit. After being neglected for half a century, it was again undertaken in 1837: I do not know with what success.

occur in calcareous beds, associated with schists and crystalline rocks, and is found in masses very near the surface.

Italy presents, in many places, valuable metallic produce, the iron ores of Elba being among the most remarkable and abundant in the world. Some other metallic ores are also found in different parts of Southern Europe.

The mines of Germany are known throughout Europe as the cradle and school of scientific mining operations. They are numerous, rich, and very varied.

The Erzgebirge, a chain of mountains separating Saxony from Bohemia, and the Hartz, the most northerly mountain range in Germany, are the principal seats of mining operations in Northern Europe, and are both of them extremely interesting; the metals obtained from them are silver, copper, lead, and iron, together with some tin and cobalt, the latter chiefly from the Saxon mines.

One of the most remarkable veins in the Erzgebirge, is the stockwork of Zinnwald, which contains veins of oxide of tin in a hemispherical mass of large-grained granite. In this district, however, the chief metalliferous ground is gneiss, and in the Hartz, also, the central granite of the Brocken is surrounded with gneiss and clay slate, and surmounted by grauwacke schist and limestones of the Devonian period, the chief localities of the productive veins being in the metamorphic rocks.

Austria possesses mineral riches of considerable value in the Tyrol, in her veins of iron ore, (with which a small quantity of gold is associated,) while in Hungary the same precious metal is obtained from veins, in which native silver, copper, argentiferous galena, blende, and iron are all present. The principal mining works in Hungary are near Chemnitz, where granite, gneiss, and mica schists form the containing rocks.

Scandinavia, under which name both Sweden and Norway are comprised, contains numerous mineral veins, chiefly in a hornblende rock bursting through schistose beds and limestones of the Palæozoic period. The ores, both of copper and iron, in this district are probably the most extensive and the richest in the world, but their position in the country rendering it exceedingly difficult to transport them, has prevented their being worked with much energy.

The Ural chain has long been remarkable for its mineral riches, and both that chain and the Altai, (separating Siberia from Tartary,) are exceedingly remarkable, as the source of auriferous sands, which have been long known, and of which there seems a never-failing supply.

The gold of Russia is chiefly obtained from these sands,\* but veins of it have also been worked of late years. The gold is contained in quartz, charged with oxide of iron and pyrites, and these minerals are often so grouped together, that it would appear as if the gold, originally entangled with the pyrites, had only been liberated by the decomposition of the latter mineral.

The silver and lead ore worked in the Altai mountains is contained in veins occurring in chlorite schist, which is sometimes crystalline and porphyritic. The mass of the vein is composed of quartz :—in the upper part of the vein the ores are ochreous, and in the lower part sulphurous, and at certain points the ore is so abundant as to replace the quartz.

\* To give an idea of the proportion of gold in these sands, I may mention, that from the year 1830 (when their existence was first discovered) up to 1835, 282,000 tons of sand had undergone the process of washing, to obtain the metal, and the quantity of gold produced amounted to about fifteen hundred pounds avoirdupois, or about the twelfth part of an ounce per ton, on an average ; but this proportion only applies to those sands which have already been sifted and prepared for washing.



The Ural chain is chiefly interesting for its copper ores, which often occur at the contact of igneous rock with limestone. It is from these mines that the finest specimens of malachite are obtained,\* and the veins also abound with iron ore, and contain both platinum and gold. It is principally on the Asiatic side of the chain that the mineral veins are worked.

South America has been celebrated for its mineral riches from the period of the first discovery of the New World, and although it was chiefly the rich gold and silver ores that originally excited the cupidity of mining adventurers, it is well known that the ores of copper and of some other metals are equally abundant, and perhaps almost equally valuable. They may be considered as forming several principal groups, of which Brazil deserves to be first alluded to being the district in which the ores of gold predominate, almost to the exclusion of all the others.

It is chiefly the mountainous province of Minas (formed of metamorphic rocks of no very ancient date) that contains those of the Brazilian mines which have been longest worked for the most precious of all metals. Gold and platinum are there found native, disseminated with ores of iron and manganese in stratified rocks. The whole district is much disturbed and broken up by the crystalline rocks in the immediate vicinity, and is intersected by dykes of porphyry and hornblende, and veins of quartz. The entire series of stratified rocks, which consist of gneiss, altered sandstones, and chloritic schists, have been penetrated throughout by metallic particles, and these sometimes become so dominant as to conceal the original character of the formation.†

\* One block of this valuable mineral has been found weighing more than forty tons: It is greatly used for ornamental purposes.

† The diamond is also found occasionally in these mines, in a white quartzose

The district in the chain of the Andes which contains the principal veins of silver ore, is situated in Peru, and includes the celebrated mine of Potosi.\* The veins here occur in clay slate, regularly stratified; the veinstone is quartz and carbonate of lime, and the metallic ores consist of pyritous ore of iron, galena, and blende; the silver being quite subordinate. These veins are generally very much inclined to the horizon, and are sometimes parallel to the stratification of the containing bed.

The Cordilleras of Chili contain an extensive series of valuable mining districts, producing much silver, associated with rich ores of copper and some gold. The ores are richer towards the north, and their value is generally increased where they approach the contact of igneous rocks with the limestones of the western part of the chain.

These limestones are of the cretaceous period, and the metalliferous veins often follow the lines of their contact with the porphyries and granites, the igneous rocks having forced their way through the limestones, and the planes of contact on each side the central axis (which runs north and south) being marked by a succession of valuable metalliferous veins. Of these veins, that series which occurs on the eastern side contains silver, and is separated by an intervening mass of porphyry, which is sterile, from other ores of silver and copper at the contact of the porphyry with granite, while still further to the west, and behind

matrix, and is associated in the same district with other precious gems, such as topaz, euclase, and beryl. The gems are contained in talcose *druses* (or crystalline hollows in veins) confusedly, and are mingled with crystals of white quartz.

\* The metalliferous ores of Potosi, the richest that are known after those of Mexico, offer a good instance of a fact not uncommon in argentiferous veins. The mineral, extremely rich near the surface, diminishes in value as it descends, and in the deeper part of the mine is scarcely one-eightieth part so rich as at the top. This is paralleled in the celebrated Dolcoath mine, in Cornwall, the deep workings of which have been for some time neglected on account of their poverty.

another range of porphyries, are the auriferous ores covered by vast masses of modern trachyte.

North of Chili, and still running parallel to the great chain of the Andes, the contact of porphyries with mechanical rocks of doubtful antiquity, but which have been altered by the action of heat, is still marked by rich veins of silver ore, upwards of six hundred of which are worked, some of them at a height many thousand feet above the level of the Pacific. From one set of these mines alone (the *Pasco* mines) about 180,000 pounds weight of silver is annually obtained; the ore occurring in masses, associated, as usual, with iron, and distributed through quartz. Still further north, in Colombia, Guatemala, and Mexico, the same abundance of mineral riches obtains, and always in the direction of the great mountain chain.

North America also, is not without rich and valuable mineral produce of various kinds, chiefly occurring in the Rocky mountains, the Andes of that continent, but also in some of the inferior mountain chains both in the west and north. Considerable veins of copper ore are found in the northern and north-western states, and abundance of iron, besides several other metals.\*

\* Amongst others, Chrome and Titanium are worked to profit in some parts of Pennsylvania. The ores of these metals were at first turned up in ploughing the fields, but they are now obtained by regular mining operations.

"What is called the *Gold region* in the United States may be described as a metalliferous belt extending in a south-west direction through the States of Virginia, North and South Carolina, and Georgia. The length of this belt is about six hundred miles, and it has a mean breadth, from its southern to its northern edge, of about eighty miles. In every part of this extensive line native gold is met with in alluvial deposits, and in various streams, whilst the contiguous rocky strata abound in quartzose veins, more or less auriferous, and either found in a formation of which talcose slate is the characteristic rock—as in Virginia—or sheathed with talcose slate, and holding an almost vertical position in elvan beds and beds of ferruginous slates, as in North Carolina; so that talcose rocks characterise the entire gold region from one extreme to the other."—*Featherstonehaugh's 'Excursion through the Slave States.'* Vol. ii. p. 350. London, 1844.

Several important results may be arrived at from a due consideration of the phenomena of the Geographical distribution of mineral veins, and the general appearances presented by them at the surface. In the first place, it would seem that they occur almost invariably in mountain districts, and are more or less immediately connected with disturbances of strata and with great lines of dislocation, or are in the immediate vicinity of igneous rocks. M. Necker, struck by these facts, which are very evident in a large number of cases, has investigated the subject of mineral veins with reference to these three questions,\* *viz.* first, whether there is any unstratified rock near each of the known metalliferous deposits? secondly, whether, if none such appear at the surface, there is any distinct evidence or any high degree of probability that an unstratified rock exists immediately under a metalliferous district, and at no great distance from the surface? and, thirdly, whether there are found any metalliferous deposits entirely unconnected with igneous rocks?

The first of these questions may certainly be answered in the affirmative, by reference to a vast number, forming the great majority, of cases of known mineral veins in all parts of the world. The great mining districts in all countries have been shewn to be immediately connected with unstratified and crystalline rocks.

In answer to the second question, M. Necker refers to a number of instances in Europe where mineral veins occur nearly and evidently associated with unstratified rocks, though not actually proceeding from or passing into them.

Such is the case, for instance, in the Isle of Elba, where an abundant supply of iron ore is obtained from veins in sedimentary rocks, but the close vicinity of erupted por-

\* Proceedings of Geol. Soc. vol. i. p. 392.

phyries and other igneous rocks, and their actual appearance at the surface not far from the veins themselves, is sufficient proof of their presence in considerable abundance.

With regard to the third question, the answer is, although not absolutely in the negative, yet sufficiently so to add great strength to any argument that might be deduced from the answers to the former questions.

The quicksilver mines of Idria in Carinthia, and the lead veins in the mountain limestone of Flintshire and the south-west of England, are among these apparent exceptions; but the former occur in a district nearly connected with the great elevations of the chain of the Alps in its continuation eastwards, and the latter are not far from considerable dislocations and disruptions of the carboniferous strata.

Besides the important fact, that the presence of mineral veins is almost always accompanied by indications of the action of subterraneous disturbing forces, and often by the actual presence of igneous rocks, we also learn, from a general consideration of the phenomena of veins, that they are, for the most part, uniform in direction in particular districts, and have a very remarkable tendency so to arrange themselves that the line of their direction shall either be north and south, or at right angles to those bearings. In England, more than half the metalliferous veins are east and west; and this is so uniformly the case in many districts, that the east and west veins are commonly denominated right running veins, while those in the other direction are known as "cross courses."

Observing how commonly it happens that mineral veins make their appearance in districts characterized by the presence of altered or metamorphic rocks, it might natu-

rally be assumed that they were chiefly confined to strata of ancient date. This appears, however, to be by no means the case, and metallic ores are known to occur in rocks of the secondary and even tertiary periods. And although the Generalisations attempted to be deduced by early Geologists as to the age of metals, are not altogether borne out by facts, there still seems to be a certain order of antiquity in their arrangement, for tin has not hitherto been met with in any rocks of modern date, nor have the precious metals been obtained from the older veins.

Apart from considerations of age, there are other circumstances, dependant apparently upon local influence in the distribution of metals, which are also worthy of notice. The slates, for instance, of Cornwall and Devonshire, are of nearly the same geological age as those of North Wales and Cumberland, but the metalliferous ores found in them differ exceedingly, tin abounding chiefly in the southern counties, copper being the staple in the central and some parts of the northern, and lead in other parts of the northern district. It is true, indeed, that copper and lead are found with the tin in Cornwall, and that lead is associated with the copper of North Wales, and Coniston Water Head; but there are indications of preference, if we may so say, which well deserve careful investigation.

It is a fact of considerable interest, that the limits of mining districts are often very decided, and marked by peculiarities in the physical features of the country. In the north of England, the neighbourhood of Cross Fell has been worked with the greatest enterprise; but no instance has occurred (it is stated by Professor Phillips) of a single vein being traced across the great Penine fault to the west. Similar facts have been observed with regard to the Flintshire veins, which occur in the carboniferous limestone, and

which in no instance enter the Silurian rocks. In this latter case, as in many others, the older rocks rise on the line of a great axis of disturbance, and seem entirely to cut off the whole of the mining ground.

Having now very briefly described the nature, the position, and the contents of mineral veins, and the incidental circumstances attending their presence in particular localities, it will be worth while to close the history with some statement of the nature of those theories, which have been suggested as sufficient to account for phenomena so remarkable and so extensively exhibited, and examine the explanations that have been offered of the most prominent and remarkable fact, namely, the original filling up of the mineral veins with the metallic oxides and metals in a crystalline state.

Mr. Necker, in the paper already cited from the Geological Proceedings, considers it a necessary result of the connexion he has successfully endeavoured to shew between veins and igneous rocks, that the method of *sublimation* was the one adopted by Nature in almost every case to fill up those cracks and fissures in the crust of the earth, which have resulted in mineral veins.

This theory of sublimation differs considerably from that of igneous injection proposed by Hutton, and both of them are diametrically opposed to the theory of aqueous deposition as promulgated by Werner. This latter cause is, however, manifestly insufficient to account for a large class of the phenomena of veins, although it may no doubt be true in some cases. It has never yet been proved possible for many of the metallic ores, and other minerals found in veins, to be so held suspended in water, that they can have been thence deposited in a crystalline state, while, on the other hand, there is every probability, from the appearance of

the veins, that heat was actively employed, although connected in many cases with other and more powerful agents yet to be considered.

The Huttonian hypothesis, that the contents of veins were in all cases injected from below in a state of igneous fusion, is scarcely more probable or better founded than the rival theory of the Saxon Geologist.

That some, indeed, of the cracks in strata, such as trap dykes, have been so injected, there can be little doubt, because in many cases we actually see the effects of heat on the rocks forming the walls of the dyke, and it is clear that quartz and many other minerals, and probably occasionally metalliferous ores, may have been forced up from below. But if this theory were really true, we should surely sometimes find the ores, as we do the basalt, protruding above the surface, and we could trace the direction of the currents in which the matter flowed, and discover some relation between the different masses of ore that occur in the veins.

With regard to the theory of sublimation, by which it is meant that the minerals and metallic ores have been volatilized by heat, and afterwards assumed their place by condensation, there can be no doubt of its being occasionally a *vera causa*; but, like the other theories, it fails in universal application. Both this and the Huttonian theory of injection would seem to require that veins should be richer in metallic produce as we descend to greater depths in a mine; but I have already remarked, that present experience is decidedly opposed to the existence of any such necessity.

The most recent attempt that has been made to account for the phenomena of mineral veins, introduces a new agency,—that of electricity; and the advocates of this



hypothesis consider, that by referring to electro-chemical action, many of the most characteristic and remarkable of the facts that have been observed may be satisfactorily explained. The great improvements and discoveries that have of late years been effected in this branch of science, and the certainty that electricity is a most powerful force, acting incessantly, and affecting even the minute structure of inorganic bodies, corresponding almost with the vital principle in its power of removing, re-arranging and selecting the particles of dead matter, render every suggestion with reference to this force worthy of the most careful attention.

The experimenter to whom science is chiefly indebted for the researches on which the electrical theory of mineral veins is founded, is Mr. Robert Were Fox, who has greatly distinguished himself by a vast number of investigations on the mutual relations of electricity and magnetism, and their mode of action in re-arranging the particles which compose the crust of the globe.

Assuming the existence of fissures produced in the solid substance of the earth's crust at various times, and taking it for granted also that they penetrate to great depths, are exposed to a high temperature, and must have been filled up progressively, Mr. Fox has shewn the probability there is of heated water having been circulated in them by ascent and descent, and the certainty that quartz and earthy substances might be deposited from water in that state. He then proceeds to explain, that in such fissures, filled with metallic and earthy solutions, the different sorts of matter on the sides must necessarily produce electrical action, which might be rendered more active by the unequal temperature of the water and the walls of the fissure. Currents of electricity thus generated would pass more easily

in the fissures than through the rocks, and they would pass in directions conformable to the general magnetic currents of the district, and therefore east and west, or somewhat to the north or south of these points, according to the position of the magnetic poles at the period when the process was going on.

Electrical currents thus circumstanced would deposit the bases of the decomposed earthy and metallic salts on different parts of the rocky boundary of the vein, according to the momentary electrical state and intensity of the different points; and the nature and position of the rocks would be influential in determining these conditions. When by such processes particular arrangements had happened, new actions might arise, and amongst them a series of secondary phenomena, such as the transformation of ores without change of form, a fact otherwise very difficult to comprehend. Lateral rents might also be filled by virtue of these new actions, even though they were not in the most favourable lines of electrical circulation.

In confirmation of his views Mr. Fox has actually succeeded, by direct experiment, in forming well-defined metalliferous veins by means of voltaic currents operating under circumstances resembling those supposed to have occurred, and which sometimes do occur in Cornwall.

Before bringing this subject to a conclusion, I may observe, as some, and perhaps a sufficient excuse for the uncertainty of our knowledge concerning it, that it is the most difficult of all departments of Geology, for it requires the closest investigation, combined with the broadest general views, while the means of pursuing such investigations are scanty and unsatisfactory, and the examination of mineral veins in the mines themselves is rarely productive of any useful result. It cannot, therefore, be a matter

of surprise that different, and even opposite views, have been advocated by those who have only partially observed Nature; and perhaps it is the safest plan, as it certainly seems the only way by which we can reconcile conflicting opinions, to take a middle course, and admit the validity of each cause that has been assigned.

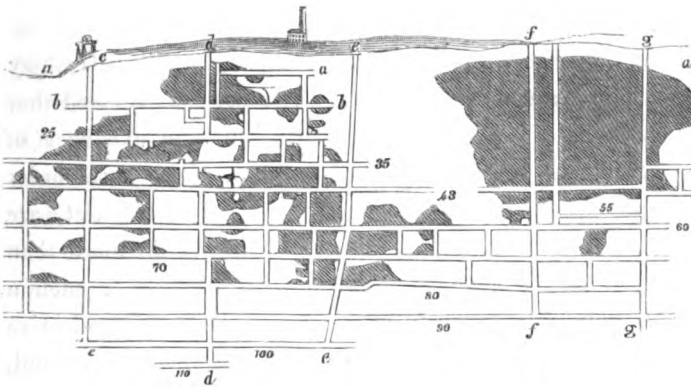
Nor is such a mode of escaping from the difficulties of the case unreasonable or inconsistent with what we know of the ordinary course of Nature, in which all means are used, and every variety of cause employed, to bring to perfection one great result. In examining the contents of veins, we cannot but be struck, not only by the appearance of a complication of causes, but by the evidence of their succession, rendering it probable not only that different agents have been employed, but that they have done their work separately as well as conjointly, that they have operated at different periods, and that one has produced effects for which another was inadequate.\*

\* See the Report of the third meeting of the British Association, p. 20.

I think it right in this place to notice a Work recently published, and from which I had hoped to derive some useful information. I allude to Mr. Evan Hopkins's book, professing to exhibit the connexion of Geology with Terrestrial Magnetism. Carrying out the electrical theory of Mr. Were Fox to its widest, I might say wildest extreme, Mr. E. Hopkins seems to me to have wandered so far into the realms of imagination as to mistake his excellent practical knowledge of certain mining districts for an universal acquaintance with the laws which govern the material universe. Dwelling on the universality of local appearances, he assumes hypotheses concerning the nature of magnetic action, which are not in any way borne out by the facts he adduces. I cannot help expressing my regret, that, in the present state of Geological science, any one should be found to generalise so extensively, and propose his generalisations to the notice of practical men with so much apparent conviction of their being well-grounded, and at the same time exhibit so very limited a knowledge of numerous facts and observations which ought to have been taken into consideration.

## CHAPTER IV.

THE NATURE OF THE OPERATIONS MADE USE OF IN DIFFERENT COUNTRIES FOR THE PURPOSE OF OBTAINING METALLIC ORES.



EAST HUEL CROFTY COPPER-MINE, CORNWALL.

*a.* adit level.

*b.* deep adit.

*c, d, e, f, g.* the different shafts.

The numbers mark the depths of the levels. The shaded portions of the diagram represent those parts of the lode that have been extracted.

ONE of the chief results to be anticipated from an extended diffusion of the true principles of Geology among practical men is, that each in his own profession will in time discover, that as there is an appearance of the action of general laws in the arrangement of the materials of the earth's crust, a knowledge of these laws will be useful in the economical operations in which he may be interested. Whatever these operations may be (and whether they refer to mining, engineering, or agriculture, it

matters not), the practical man must in time study and observe for himself, and he will then learn to anticipate with certainty what result will take place from a known combination of circumstances. The effect of a series of observations carried on by intelligent men possessing a fair knowledge of Geology, might, and probably will, ultimately, tend more to the advance of Geological science than the comparatively desultory work performed by the amateur, who is necessarily obliged to traverse with rapidity a district in which the constant resident finds many opportunities of study and investigation.

With regard to that department of practical Geology which we are now considering, it must be confessed that at present the indications furnished of the existence of metalliferous ores by a consideration of the general order of superposition and age of the rocks of a district, are rather negative than positive, and scarcely do more than enable the Geologist to assert, that in such or such a spot there is no probability of the existence of productive veins. Still even this amount of knowledge is useful, and a more minute acquaintance with the disturbances and dislocations of the strata in a district already known to be metalliferous, is calculated to afford indications of the utmost value, and form a branch of practical Geology, from the careful pursuit of which the most interesting results may be anticipated.

And after all, the discovery of the existence of mineral riches in a district is by no means a point of practical difficulty, while to decide whether such produce will repay the expense of bringing it to the surface and exporting it to distant countries must always depend very much on local circumstances, which have little immediate relation to Geology.

By examining the beds of mountain streams, and the gravel or loose stones brought down into the plain country, a knowledge of the existence of metalliferous veins in a district may often be attained. By following up the indications thus afforded, an idea of the actual position of the veins, and even of their extent and value, may also be acquired. This simple method was, no doubt, the one by which many of the richest veins were originally discovered, and it is still so far pursued, that sifting the gravel and sand of many rivers in metalliferous districts is to this day a profitable undertaking, and in some cases is the only kind of research pursued.

“Stream-works,” as undertakings are called in which this method of obtaining ore is pursued, are in our own country chiefly or entirely confined to the ores of tin, which, from their great specific gravity, are readily separated by the action of running water from the lighter sands and gravel with which they are associated. The ores of tin worked in the island of Banca, in the eastern Archipelago, are entirely obtained in this way, and the quantity of ore brought down by the mountain torrents may be imagined when it is mentioned, that as much as 3,500 tons of tin have been exported annually from that island alone.

In other cases, gold or silver, in a virgin state, is distributed in small grains in the sand, and this is, in fact, the chief source of the precious metals from many districts in Europe, Asia, Africa, and even some parts of America.

The sifting and washing of sand furnishes in this way nearly all the gold produced in Russia, both European and Asiatic; the gold being found nearly pure, and mixed only with a small quantity of silver and platinum, in the state of small grains. An annual supply of about fifteen

thousand pounds weight of gold, and nearly five thousand pounds of platinum,\* is thus obtained, (the latter metal chiefly from the sands of one stream), of which more than three-fourths is derived from the Altai mountains, which separate Siberia from Tartary.

In our own country, the stanniferous gravels of Cornwall are not usually upon the surface, but are either covered with other gravel, or with clay, sand, or peat, which require to be removed before the fundamental rock is reached on which the tin-stones rest. The gravel when collected is thrown upon an inclined plane, upon which a fall of water is conducted, and then being worked about, the tin-stones, if of sufficient volume, and provided the force of the water is not too great, remain upon the inclined plane, while the lighter stones and earth are washed away.

It is from this method of separating the ore that such works have been called stream-works. They are of comparatively small importance now in reference to the general supply, but still afford employment to a number of the poorer miners.

As, however, such a source must be, at the best, doubtful and uncertain, and one which in most districts would soon fail, it becomes necessary that the gravel should be gradually traced along the bed of the stream, by whose rapid current it has been brought down, until the metalliferous fragments of rocks, increasing in number and volume, at last point to the spot where the outcrop of a vein at the surface has been the origin of the supply.

\* Some interesting observations have been recorded by the Russian mining engineers with regard to these auriferous sands. It has been remarked, that they rarely repose on granite or syenite, but usually on schistose rocks, near serpentines and hornblende rocks. They are also found, not in the recesses of the mountains, but principally forming plateaux parallel with and terminating the chain, or exhibited in the lower and broader part of the valleys. They are not continuous, and in certain localities the gold is more abundantly distributed than in others.

This method of arriving at the actual position of the vein is called in Cornwall, *shoding* or *shoadling*,\* and is a method of great antiquity, being in fact an almost necessary preliminary to any regular mining operations. When the ore is thus discovered at its source, it is not difficult to determine whether it is a thick bed of gravel, a vein, or a mere lump of ore, and its direction and relations with the surrounding country may be more or less clearly made out.

The early history of the Cornish mines, and the nature of mining operations in that country at the commencement of the seventeenth century are recorded in a very interesting manner by Carew.† “He first notices stream-works and lodes, and the opinion of the tanners that the tin-stones in the stanniferous gravels were derived from the lodes by the deluge. He next describes the process of shoding, which seems to have been then conducted much in the same manner in which it is now practised, and he notices that the shode for the lodes ‘either lieth open upon the grasse or but shallowly covered.’ Having found this shode ‘they next,’ he says, ‘sank pits of five or six foote in length, two or three foote in breadth, and seven or eight in depth, to prove where they may so meet with the load. If they miss the load in one place, they sincke a like shaft (pit) in another beyond that, commonly farther up towards the hill, and so a third and a fourth until they light at last upon it.’”‡

If the lode thus discovered offered a fair prospect of success, the discoverer would usually associate others with

\* The fragments of ore which by rain or currents of water are torn off from the lodes or veins of ore, are called *shoads*.

† Survey of Cornwall, by Richard Carew. (Reprinted 1769.)

‡ De la Beche's Report on the Geology of Cornwall, Devon, and West Somerset, p. 527.



him in the working, and the company of adventurers thus formed appointed a captain, whose duty it was to see that the men did their work properly, and who attended to the mine and to the pumps. The tools used were extremely simple, and consisted only of a pickaxe and shovel, but with these they would sometimes follow the lode to the depth of forty or fifty fathoms, the miners being let down and taken up by a rope wound over a winch. In cases, however, where the hang or inclination of the lode was considerable, the miners are described as working to a convenient depth, when they sunk a shaft from the top "to admit a renewing vent, which notwithstanding, their work is most by candlelight." The loose work was kept up by timber, and the rate of progress appears to have been very slow, as we are told, "a good workman shall hardly be able to hew three foote in the space of as many weeks."\*

It will readily be imagined, that into pits thus sunk a considerable quantity of water would drain, and it is clear that this was an extremely troublesome and unmanageable difficulty, often inducing the abandonment of a valuable mine. The draining machinery is described as "composed of pumps and wheeles driven by a streame, and interchangeably filling and emptying two buckets and such like." In some cases, when the works were on a hill-side, canals were cut from the lode to the nearest convenient valley, but they are described as being "costly in charge, and long in effecting." And even where these difficult and expensive means were resorted to, the water would still have to be raised from such of the workings as were below the level of the valley, and a speedy limit would be put to all workings where the ore lay deep beneath the surface of the surrounding country.

\* Carew, *ante cit.*, p. 10, 11.

The description thus given of the superficial, and comparatively simple works of a former age, is applicable in a very considerable degree to the more extended operations of the present day; for, although the introduction of improved machinery has tended to increase the facilities of working at great depths, the only difference in principle is the establishment of an improved plan of working adapted to the nature of veins of different kinds, together with that attention to ventilation necessary in all underground operations that are at all extensive.

The various operations which are included under the general expression "the working of mines,"\* may be conveniently grouped under two heads, the first having reference to the preliminary and experimental works necessary to be undertaken before the commencement of mining on an extensive scale, and the actual processes of sinking shafts, driving galleries, detaching the ore from its matrix, and bringing it to the surface, &c.; and the second comprehending what may be called the incidental works of a mine, those namely, of drainage and ventilation, without a due attention to which no mine can be safely worked at all, while, on the careful and scientific attention to such details, the safety of the miners and the profit of the mining adventurer mainly rests.

\* The French term 'exploitation' expresses much better than our English word, 'working' the important and varied nature of mining operations.

"L'exploitation des mines," says M. Burat, "embrasse tous les procédés, moyens, ou méthodes qui ont pour but l'extraction des matières utiles; cette extraction devant toujours être sûre pour les travailleurs et aussi économique que possible. Cette science doit encore définir le gîte, veiller à son aménagement, afin de préparer et conserver pour l'avenir les garanties de sécurité et de richesse. La science de l'exploitation, ainsi composée de principes, de procédés et d'appareils dérive à la fois des sciences géologique, physique, et mécanique; elle comprend en outre des faits spéciaux et des données pratiques qui sont acquis aujourd'hui par les travaux de tous les hommes distingués qui en ont fait l'objet de leur études." *Géologie appliquée*, par A. Burat, p. 218.

The operations included under the first head, will be the objects of consideration in the present chapter, while the others, having reference to the extraction of mineral produce from stratified deposits, as well as from mineral veins, will be more properly discussed after I have spoken of coal, and other substances obtained in a similar way.

The preliminary operations of mining are necessarily dependent in a great measure on the nature of the rocks, whether they are penetrated by mineral veins or interstratified with mineral treasure, and on the amount of knowledge possessed concerning the general structure of the district, and the extent to which similar works have been carried. They must also differ according as the mineral to be extracted is supposed to exist near the surface or at great depths.

The indications on the surface that may be presented by a mineral vein, are not usually sufficient to attract general attention, and would in most cases be so entirely hidden by a coating of gravel and vegetable soil, as to exhibit scarcely any marks that would enable even the most experienced eye to recognise them. In the absence, therefore, of metaliferous gravels which can be traced up the course of a stream to a hill-side, and to the actual outcrop of a vein, (and even then wherever many veins intersect,) the question must often be determined more by experiment and tact, than by any distinct indications of the spot in which it will be most advisable to commence sinking, so that the greatest advantage shall be derived from the vein, supposing one there to exist. In cases where the existence is doubtful, but a probability appears of mineral veins being discovered, a series of experiments called in Cornwall '*costeaning*,' is undertaken with the view of discovering the presence of a vein. This method of experimenting is derived

from the supposition that the veins in the district follow some general law, and the operators, selecting a convenient spot, commence by sinking a pit through the soil, and to a small depth in the rock. Of course the chances are many against immediate success, but in case they find nothing, the next step is, to *drive* or cut a gallery from the pit a short distance in opposite directions, at right angles to the direction of the lodes found in the neighbourhood. In this way it is possible that they may 'cut the lode;' but if still unsuccessful, they remove a few fathoms in the direction of the galleries, and repeat the same process until they have either discovered the lodes, or give up the speculation in despair.\* In matters of this kind, although experience is often a better guide than abstract science, still there is no doubt that the person best able to bring his experience to bear will be one who is acquainted with the facts of Geology; and such an one will avoid many sources of error, because his conclusions will be founded on rational premises. The great secret of economical mining lies in the original adoption, and proper carrying out, of an uniform and well-digested plan of working, a plan that can only be properly laid by the experienced mining engineer, who is able to add an acquaintance with Geological facts to sound practical and local knowledge. I am indeed most anxious to impress upon every one who reads these pages that,

\* I would not here so far offend against the common sense of my readers as even to allude to the absurdity, did not some practical men in our own country still credit the fable, that mineral veins may be discovered by a forked hazel twig, dignified by the name of a divining-rod. In the year 1830, and possibly at the present day, a person living at Redruth was so far notorious for his enchantments of this nature, that he was quoted with some degree of consideration in the Quarterly Mining Review, vol. i. p. 403, and others, perhaps, may be equally celebrated. I merely allude to the subject as a *quasi* method of discovering mineral ore and subterraneous springs, which may still be had recourse to. The prospects of success from the employment of such means I leave to the consideration of speculative miners.

while the mere Geological theorist may be even more likely to fall into error in some cases than the mere empiricist or 'practical man,' it is the intelligent observing experimenter who is sure to succeed, and will most certainly enlarge the bounds of knowledge, as well as benefit himself and all who confide in his guidance.\*

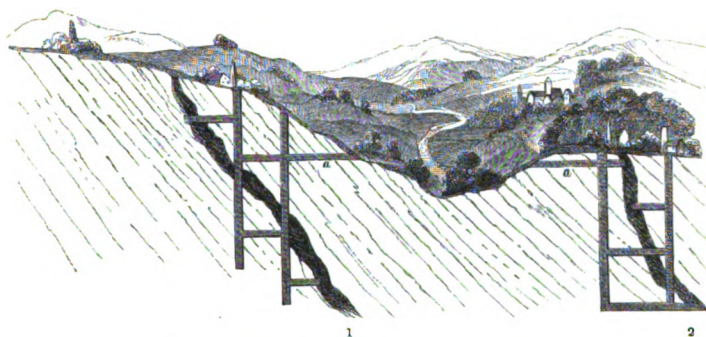
When the position of a mineral vein is ascertained, its direction known, and some reasonable conjecture made concerning its extent, thickness, and value, measures must be taken to obtain by subterraneous excavation the buried mineral, † and for this purpose pits or shafts must be sunk, and galleries, or, as they are sometimes called, *levels*, must be driven, which prepare the way for the convenient extraction of the ore, and at the same time carry off, so far as may be, the water which either rises into the mine from springs or drains into it from the surrounding strata. ‡ Of such galleries, two sets must be driven at right angles to

\* Many interesting and valuable exemplifications of this truth are recorded in the life of William Smith, "the father of English Geology," as he has been in some respects justly called, recently published by Professor Phillips. It appears that the really scientific knowledge of Mr. Smith, acquired by the application of a philosophy purely inductive, was often available, and employed in purposes and results entirely practical. Improvements in draining of all kinds, and many ingenious contrivances in the laying out and constructing of canals, were suggested to him in consequence of the knowledge he had attained of the facts of stratification, and were of the most vital importance in many engineering operations on a large scale.

† I have confined myself in the text to a description of those works in which subterraneous operations are necessary. All mining undertakings are of this kind at some time or other, and till then they partake rather of the nature of quarries, to which I shall allude more particularly hereafter.

‡ In the ordinary language of mining, pits open to the surface are called *shafts*; and in Cornwall those not open to the surface, but sunk from one gallery to another, have received the name of *winzes*. Horizontal galleries, excavated in metalliferous veins, are called *levels*, and those not in the metalliferous veins, *cross-cuts*; but that principal gallery, or tunnel, through which the drainage of a mine is conveyed to the surface at the lowest convenient spot, is denominated the *adit* or *adit-level*. All excavations horizontally are called *driving*, those downwards *sinkings*, and those upwards *risings*.

each other, and both horizontal, one being in the direction of the strike of the vein, and the other at right angles to that direction.



VIEW AND IDEAL SECTION OF MINERAL VEINS.

Let us suppose a simple case like that represented in the cut, in which mineral veins crop out on the sides of a hill and follow a direction tolerably uniform. These veins let us assume to be of moderate thickness (not exceeding a few feet), extending to an unknown depth, and not greatly interfered with by faults.

In such a case a pit must be sunk which shall reach the vein at a certain depth, but it will depend on the direction of the dip, or underlie, of the vein, (whether *towards* or *from* the valley or slope of the hill-side,) and on many other circumstances, as to where it will be most advisable to commence the sinking. In the case of the vein marked (1) a cross-cut (*a*) may be driven at the lowest convenient point above the level of the highest water of the valley, and this gallery, having a gentle slope from the vein towards the hill-side, will form the adit-level, and be the channel through which the whole drainage of the works will be carried, while it may also serve for conveying out of the

mine the ore that is obtained. At (2) in the same sketch, the driving of an adit level ( $\alpha'$ ) will be seen to offer similar advantages, but a difference will be observed in the arrangement of the shafts. In both cases it is found advisable to sink shafts on the upper side of the vein, but in (2) it is also convenient to have a sinking towards the slope of the valley, and which does not cut the vein.

The shafts sunk upon a vein are not always vertical to meet the vein, but are occasionally commenced at the outcrop, and, where the inclination is not very considerable, are continued in the substance of the vein itself.\* This is not, however, so economical a process as it may appear, for the difficulty of raising the ore is much increased, and there are many practical reasons which often render it expedient to sink at some distance from the outcrop so as to meet the vein at a certain convenient depth.

The act of sinking a perpendicular shaft downwards to a depth where it is calculated the lode should be cut, may seem to require little further skill than is necessary to determine correctly the spot on the surface where the work is to commence. But the process in this way is exceedingly tedious, and in a mine at work where many galleries already existing are to be traversed, much greater rapidity is desirable. In such a case,† the shaft is sunk in several *pieces*, or, in other words, the sinking is commenced at the same time in several different levels, and no small skill is required so to lay out the work that the different portions of the shaft thus formed may exactly fit when they are connected together. An exceedingly small error of measurement in any one of these various and dark subterranean passages, would, in fact, be sufficient to throw the whole

\* In the diagram at the commencement of this chapter, the shaft ( $e$ ) is a slant shaft, particularly in the deeper sinkings.

† See diagram at the commencement of this chapter.

into confusion, but such an accident rarely happens, although works of the kind are common in the Cornish mines.\*

In the same way, to drive an adit from one point to another through many fathoms of country requires great skill, more particularly where, in order to save time, the work is commenced from both extremities. Less than a quarter of a century ago (in 1824) great complaints were made in Cornwall of the condition of these channels; and the necessity of attending carefully to the details of draining was insisted on, and the proper position of the adit pointed out by Mr. Carne. Owing to neglect in these matters, and to the want of good surface draining, a large quantity of water pumped up from the deep mines found its way back again among the workings, and this happened to so great an extent that since that period, greater attention having been paid to drainage, the quantity of water pumped is considerably diminished although the mines have become deeper and more extensive, and in many mines, where great care has been taken with reference to this subject, the improvement has been very striking. Some idea may be formed of the extent of the drainage in mining districts from the fact that the various branches of the principal level in Cornwall, called the "*great adit*," which receives the waters of the numerous mines in Gwennap and near Redruth, measure on the whole, about 26,000 fathoms, or nearly 30 miles, in length. One branch only (at Cardrew mine) extends for nearly five miles and a half, and penetrates ground seventy fathoms beneath the surface. The water flows into a valley communicating with a small inlet of the sea, and is discharged about forty feet above high-water mark.†

\* De la Beche's Report, *ante cit.* p. 563.

† The total quantity of water discharged from mines in Cornwall by steam-



In very extensive mines, such as are worked in Cornwall, it is necessary to have many shafts and a very considerable number of levels and cross-courses in order to carry on the general work of the mine.\* In such cases there is usually a principal shaft of considerable size sunk through as many lodes as possible, and communicating with all the galleries. This shaft is often double; one portion, called the engine shaft, being used only to convey the water from the deep workings to the adit level, and the other, the whim-shaft, to raise the ores to the surface. The two shafts are in these cases close together, and are united at convenient distances by short cross-cuts.

It is always of importance to sink a shaft in such a way as to communicate directly with as many as possible of the lodes worked in a mine when, as is usually the case, several veins occur running in the same direction, and at no great distance from one another. In the Fowey Consols mine in Cornwall as many as thirteen lodes are worked, and they are so near each other that one shaft (the UNION) cuts through five of the lodes, and by means of a cross-cut at the sixty-fathom level, communicates with all the rest. The workings on different lodes are connected with each other by means of cross-cuts, so that the ores may be

engines, in 1837, amounted to about thirty-seven millions of tons, and the average number of engines at work was about seventy. The average discharge per minute in the Fowey Consols mine in the same year was fourteen hundred and seventy gallons, the greatest depth of the workings being one hundred and sixty fathoms (nine hundred and sixty feet) below the adit. The Dolcoath mine is much deeper (reaching two hundred and twelve fathoms below the deep adit), but the lower part is now, and has been for some time, filled with water.

\* The total amount of sinking in the Consolidated mines in Cornwall is stated by Mr. Taylor to amount to more than twelve miles of perpendicular depth, (including, of course, the winzes or underground shafts,) and the horizontal galleries extend to as much as forty miles in length. Parliamentary Report, 1835. Accidents in Mines. Qu. 1843.

brought to the shaft not only in the course of the lodes, but also at right-angles to their courses.\*

The lowest part of the engine-shaft, called the *sump*, is usually sunk a certain depth below the lowest workings, so that the drainage of the mine makes its way into it. It is, however, also important that each successive level should be separately drained in order that as little water as possible may descend to these lower workings. The water raised is delivered at the adit-level, and so escapes at the natural drainage-level of the district.

The depth to which shafts are sometimes sunk below the level of the surrounding country is sometimes very considerable. The Dolcoath mine, long celebrated for the depth and magnitude of its workings, reaches to more than 210 fathoms below the adit-level, which is itself thirty or more fathoms below some parts of the surface. The main shaft of the Fowey Consols is but little inferior, and there are several other mines both in Cornwall and elsewhere worked to a great depth.†

\* These cross-cuts must be understood as having no reference to *cross courses*, which are unprofitable veins traversing the lodes at right-angles. Great advantage, however, is sometimes obtained in mining, by observing the peculiar circumstances connected with the traversing a lode by the cross courses. Sometimes the latter are scarcely touched, being only crossed at right-angles in working the lode; but they are occasionally used to drive adits upon. The cross courses are also generally connected with faults, and sometimes they heave the lode, and bar the progress of the miner, while at other times they tend to keep out the water accumulated in the old workings of a neighbouring mine. It will be manifest that a considerable amount of practical knowledge must be required to enable the miner to venture on any speculations in a matter of so much importance, and that an accurate notion should be had of the true mechanical condition both of the lode and cross courses, before any undertaking, that depends for its success on their mutual influence can be safely commenced. In such a case a false theory is worse than no theory at all; and therefore it is that such speculations as those propounded by Mr. Evan Hopkins (see ante, p. 278), whose opinion as a practical miner is no doubt very valuable, are likely to be exceedingly mischievous, unless they are counteracted by more sober reasoning, and wider views of more numerous classes of facts in different mining districts.

† The Tresavean, the deepest mine in Cornwall, is now worked at a depth of

In these cases the difficulty of mining is increased by the high temperature experienced in the workings,\* but the veins can hardly be considered to exhibit any very decided and uniform change in the value or amount of their contents, although in some cases ores of different metals seem to abound most within certain particular limits of depth.

The underground work of a mine depends chiefly upon the magnitude of the vein, and the value of the ore to be extracted. The vein once reached, either by the shaft or by the cross-cut carried horizontally from it, levels are driven at different depths (usually about ten fathoms, but depending greatly on the nature of the mining ground), and the whole horizontal section of the lode on each level is excavated by galleries. In many cases the lode not being more than a few feet in width, one such gallery is sufficient, and as it is only necessary to leave a passage wide enough to extract the ore, the levels at those places where the lode is narrow, or *nipped in*, are very narrow and confined. Where the lode is broader, and also rich, the open spaces are of course much larger, but there can scarcely be any rule in a thing so variable as a mineral vein, for the breadth of the parts worth working, though small and with little ore in some places, may be several feet across in others and extremely rich, or the vein may be thin and rich in one place, and broad and comparatively poor in

upwards of three hundred fathoms; and a machine has lately been erected there, by which the miners may be raised or lowered as much as two hundred and forty fathoms. The advantage of this machinery has already been greatly felt, and it must ultimately be introduced into all deep workings.

\* The increase of temperature in deep mines appears to vary according to some law which is not at present understood. At the depth of sixty fathoms the temperature is independent of atmospheric changes, and is about 60° Fah. At one hundred and thirty-two fathoms it is said to be 70°, and at two hundred and forty fathoms, 80°. According to Mr. Henwood the increase becomes more rapid at greater depths.

another; so that it may even be a question whether it is advisable to take that portion out at all. \*

There are, however, distinct methods of proceeding when it is required to extract very large masses of ore, and in those cases where the horizontal section is too large to be at once excavated, pillars are left to support a roof, and cross galleries are driven, intersecting one another. In order to avoid loss as much as possible, it is necessary in such cases to make the galleries lofty, and artificial support is given to the roof by timbering: but accidents can hardly be avoided when this method is carried on to a great extent.

Connected with these operations of mining, and so contrived as to effect the required purpose in the best way, are the arrangements made for a proper supply of fresh air in the workings. The means of obtaining this are simple, where there is no evolution of noxious gas, and they consist chiefly of making a proper use of the numerous shafts, and of the communications effected from shaft to shaft by the different levels or galleries. When these communications are properly made, currents are found to set in different directions, varying probably according to the temperature of the atmosphere at the surface and the known increased temperature at considerable depths under ground,

\* De la Beche's Report, p. 561. Sir H. De la Beche adds, "These are matters on which the chief agents decide according to their skill and judgment. It is usual in mines, particularly those worked on a large scale, and for a continuance, not to take out all the ore which could be immediately got at, if thought necessary, but to leave it here and there, to be worked as the general prospects of the mine may require, and to which the miners return if less ore is raised generally in the adventure than could be wished. The ores thus left in various places are called the *eyes* of the mine; and when it may be necessary, in abandoning the mine, or from any pressing circumstances, to remove them, it is termed '*picking out the eyes of the mine.*' In some mines these eyes are very valuable, and much skill and judgment is employed in so arranging the workings that a general good supply of ores may be obtained."

and it is rare that any mechanical means are resorted to for ventilating the mine, except in such cases as where a level is in progress to communicate with a shaft. Generally speaking, the air becomes vitiated to such an extent that candles cease to burn brightly, long before it is sufficiently bad to destroy life; and, in fact, it is so impossible to continue to work a mine in this state that accidents rarely happen.

The veins of copper and tin, common in Cornwall, are for the most part not sufficiently thick to require any extraordinary method to be employed in extracting the mineral riches, but timbering is necessary to avoid the danger that would arise from the sinking in of the upper side of the vein.\* In Derbyshire, and Alston Moor, however, whence the chief supplies of lead ore in England are obtained, the veins traversing the mountain limestone swell out and become productive chiefly or entirely in one bed of limestone,† and they there attain so great a thickness as to admit of being extracted by methods very different from those necessary to be resorted to in the Cornish mines.

There are certain local names‡ given to peculiar forms of mineral veins in the north of England, to which I have already alluded, but there are others which must be now explained, while referring to the mining operations of the district. The most common of these veins is the *rake* vein, which is a vertical crack or fissure, or rather a group of such fissures parallel to each other, and frequently crossed

\* The quantity of timber used annually in the Cornish and Devon mines is very considerable, and consists almost entirely of Norwegian pine. Sir Charles Lemon having counted the rings of annual growth on several of the trees, considers that the average age of the timber employed in the Cornish mines is about one hundred and twenty years, and that it would require one hundred and forty square miles of Norwegian forest to afford a supply for these mines.—De la Beche's Report, *ante cit.* p. 573.

† See *ante*, p. 253.

‡ See page 248.

at right-angles by small *pipe* veins; these *pipe* veins, the most important to our present purpose, are, in fact, horizontal expansions of the vein between certain beds of limestone, and are filled with the mineral matter which forms the matrix of the ore (barytes, fluor spar, calc spar, &c.)

The appearance of one of the larger pipe veins is very curious, the vein being only rich where it expands on entering a particular bed of limestone. In the Alston Moor district there are many instances of this kind in the lead mines, and others are known in which rich ores of iron are worked, the masses of mineral substance being so extensive as to fill expansions of a vein which when excavated leave vast subterranean caverns.

In order to obtain the ore from the vein, and break it into masses of convenient size, many processes have been formerly employed, which have almost all given way to that of blasting with gunpowder. By the Saxon Geologist, Werner, rocks were divided into five classes, according to their degree of hardness, the first being sandy and friable, and capable of being removed with the spade, and the second including those rocks of moderate hardness, such as coal, the oolitic limestones, gypsum, shales, and slates, which require to be dislodged with the pick and removed in masses by the aid of levers and simple machinery. The third class of rocks includes those which are harder, but still not so hard as to strike fire with flint, and they may be removed partly by blasting, but chiefly with common picks, levers, and such simple machines. The fourth and fifth classes comprise rocks both hard and tough, and also those which are splintery, and they cannot be at all touched except with blasting, and even then sometimes scarcely repay the trouble and expense of working. The ancients, before the use of gunpowder was known, em-

ployed fire to fracture these rocks, and in some of the mines, both in Saxony and Hungary, this custom is still continued ; a large rectangular box containing fire being placed before the naked surface of the rock until it is sufficiently heated, and then water being thrown upon the heated portion to crack and fracture it, and allow the workmen to remove it with the hammer, pickaxe, and other instruments.

The employment of gunpowder in mines dates as far back as 1632, and since that time the labour of extracting the mineral produce in the great majority of mines has been very considerably reduced. The powder acts by the sudden and violent liberation of a quantity of gas, amounting, when the gas is incandescent, to between four and six thousand times the original volume of the powder; and the expansive force thus created is of the most active and energetic kind, and is especially useful in subterraneous works.

The method of using this great, and, in mining operations, most manageable power, consists in piercing a hole in the solid rock in places where the escape of the liberated gases is impossible without fracturing the rock itself. A cylindrical hole being thus formed, a charge of powder is introduced, varying of course with the nature of the rock and the magnitude of the work to be done ; and the charge being fired by a train of powder or a fuse, the miner has time to get out of danger before the explosion takes place.

The process of blasting, in spite of the greatest care on the part of the miner, has often been the cause of fearful accidents, and these must continue so long as the old system of firing is adhered to ; but the danger is now happily removed by the invention of a safety-fuse, introduced of late years, and at the present time, I believe, used in nearly all the mines of Cornwall.

This fuse possesses three great advantages : First, that of certainty, and this is the same whether the ground be wet or dry ; secondly, that of safety : in one instance alone in the Kingstown Harbour, nearly 75,000 lbs. weight of powder having been fired by this means since 1833 without a single accident, and numerous other similar examples being on record ; and, thirdly, that of economy, since the quantity of gunpowder saved repays the expense of the fuse. It is, indeed, so cheap, that it is no longer worth the while of the miners to make the common fuse when the safety-fuse has been once introduced.

The fuse is about one fifth of an inch in diameter ; it has the appearance of a varnished cord, and burns slowly at the rate of eighteen inches per minute. By its means the charge may readily be lodged at any required depth in the rock, and any number of shots may be simultaneously fired. It has also the advantage of perfect simplicity, being more easily applied than any other process.

Before the application of the safety-fuse several improvements had, indeed, been suggested, and, amongst the rest, the substitution of a copper needle instead of an iron rod to be inserted during the *tamping* or plugging the hole, and after the withdrawal of which the communication was made for firing the charge, and Mr. R. Were Fox had invented a contrivance, by which this dangerous mode of tamping or ramming in fragments of loose rock might be avoided. By the use of the safety-fuse, and with proper care in its application, scarcely any danger now remains.\*

The last operation connected with mining that I shall

\* I have dwelt at some length on this subject, and I would hope that the contrivance I have alluded to, (and which is patented by Messrs. Bickford, Smith, and Davey, of Camborne, Cornwall,) may attract the notice of such practical miners as have not yet availed themselves of its advantages. I make no apology



allude to in this chapter, is that of bringing the ore to the surface, which I shall consider only so far as the mechanical contrivances required are connected with the general working of the mine.

After the ore has been detached from its matrix, it is necessary, of course, that it should be transported, in the most convenient way, to the bottom of the shaft, up which it is to be brought to the surface; and in those cases in which the quantity of metal is small compared with that of the stone to which it is attached, and where the metal is not one of great intrinsic value, this becomes a matter of very considerable importance, and adds greatly in extensive mines to the expense of working. To diminish this

for pressing strongly on their attention an invention which has already exhibited such important results in preventing the loss of human life.

Some idea may be formed of the extent to which blasting is carried in mining operations, when it is known that as much as three hundred tons weight of powder is used annually, in Cornwall only, for this purpose. I also subjoin a table of considerable interest with reference to this subject, published in M. Burat's "*Géologie appliquée*," p. 232.

Result of blasting in the mines of Saxony and Bohemia, in galleries of the ordinary dimensions per cubic metre :—

	Quantity of Powder.	Hours of Work.	Dimensions of Gallery.
Compact quartz, and quartz vein-stone, .	6·80 kil.	210	1·90 × 1·20 metres.
Very hard and tough gneiss, . . .	4·64	171	2· × 1·
Silver ore in a hard vein-stone of gneiss, . . .	3·88	143	2· × 1·
cemented by quartz paste, . . .			
Ditto in a vein with clayey <i>salbandes</i> , . . .	2·20	111	2·10 × 0·85
Ditto in a vein of gneiss, cemented by argillaceous paste, . . . . .	1·30	66	2·47 × 1·
Ditto in a smaller vein, not gneissic, . . .	0·82	39	2·47 × 1·47

It will be understood, however, that, independently of the hardness of the rock, its crystallographical condition, and the nature of the cleavage it possesses, have a very great influence on the result.

I have not thought it necessary to reduce these measurements to the English standard, because their chief value arises from the proportions that obtain. The following, however, are the values of the French measures :—

1 metre = 1·0936 yards.  
1 kilogram = 2·2055 lbs. avoirdupois.

expense as much as possible, tramroads are now commonly used, and the dimensions of the waggons, or corves (from the German *korb*, a basket,) very carefully calculated; but in many mines, more especially those in South America, human labour is still employed, men, and even women, carrying on their heads heavy weights up the numerous and steep ladders that communicate with the upper ground. In France and Germany, and in our own country, human labour is also employed, although chiefly in propelling, or drawing along underground galleries, the loaded waggons charged with the mineral produce of the mine.

Great improvement has been effected of late years in the facility of transporting the ores underground, by the introduction of such small tramroads and waggons, instead of the old practice of wheelbarrows and planks; and the saving of expense thus effected is very great, amounting, in fact, to one half the former cost. Many extensive mines are provided with miles of this subterraneous railroad, and the advantage is greater, because for the most part there is a slight descent from the workings to the bottom of the shaft, to allow of a more complete system of drainage than could otherwise be attained.

The ores are usually lifted by machinery from the bottom of the shaft to the surface, and in all extensive mining operations this machinery (the *whim*) is worked by steam-power; but although steam-whims are now common, horse-power is still used to some extent. The quantity wound up at one time varies, but sometimes amounts to half a ton, or more. In a very few instances inclined planes assist in raising the ore, but it is only under peculiar circumstances that they can be used with advantage.

## CHAPTER V.

### ON THE PREPARATION OF ORES, AND THE GENERAL STATISTICS OF MINING IN DIFFERENT COUNTRIES.

THE various processes by which metallic ores, after being brought to the surface, are prepared, and reduced to the condition of pure metal or to a marketable form, must necessarily depend so much on the particular ores extracted, on their chemical and mineralogical condition, and even on the mechanical condition in which they are found, that each different class requires, to a certain extent, a special description. I shall devote the present chapter to a consideration of the methods of reducing the ores of greatest economical importance, alluding, as occasion may seem to admit, to the statistical history of the mining districts in which they occur.

Copper, of which the ores are chiefly met with in Cornwall, is, next to iron, (of which I shall speak hereafter,) the most important and valuable of the metals found in England; and as it is usually associated with tin in the mines in which it occurs most abundantly, I shall first speak of these two metals, of which the quantity annually obtained exceeds in value a million-and-a-half sterling.\* Lead and zinc, the most important metals in England, next to iron and copper, will be afterwards considered with reference to the mines in Derbyshire and Yorkshire.

\* The following table will serve to give a general idea of the relative abun-

The chief ore of copper found in the south-west of England is the bisulphuret, or that which is called copper pyrites.\* It contains, when pure, nearly equal parts of sulphur, copper, and iron, but in the lodes is often mixed up with other substances, such as sulphuret of zinc, iron and arsenical pyrites, quartz, chlorite, and other minerals, so that, although considerable masses of the pure ore are seen occasionally, it is usually so much mixed as to require *dressing* previous to sale. Its average price in 1838, when prepared for sale, was *5l. 17s. 6d.* per ton of 21 cwt.

The next important Cornish copper ore is the sulphuret, or grey ore of the miners, and it contains more than 77 per cent. of copper, 20 per cent. of sulphur, and a very little iron. Many variable compounds, however, pass with the

dance and value of the mineral produce obtained from the different countries in Europe. It is chiefly deduced from M. Burat's work, already quoted.

	Proportionate produce.	Tin.	Copper.	Mercury.	Zinc.	Lead.	Iron.	Silver.	Gold.	Value in £. <sup>s</sup> sterling.
		Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	lbs.	lbs.	
British Isles . .	1000	3600	12,000	—	2,000	46,000	1,350,000	6,000	—	17,600,000†
Russia and Poland	285	—	3,300	—	4,000	600	300,000	38,500	12,000	5,400,000
France . . .	250	—	80	—	—	400	430,000	3,314	—	5,280,000
Austria . . .	154	20	3,500	250	75	4,500	70,500	42,500	3,250	2,680,000
German Confederacy	143	300	2,000	650	—	8,000	70,000	5,350	60	2,580,000
Spain . . .	125	—	25	1,750	85	20,500	15,000	—	—	2,160,000
Sweden and Norway	123	65	1,240	—	300	40	85,000	10,350	4	2,160,000
Prussia . . .	111	—	540	—	800	6,000	70,000	10,000	—	1,960,000
Belgium . . .	91	—	—	—	1,750	325	162,000	350	—	1,600,000
Tuscany, Elba, &c.	32	—	—	—	—	—	24,000	—	—	600,000
Piedmont, Switz- erland, Savoy, &c. }	27	—	—	—	—	350	22,750	1,250	13	440,000
Denmark . . .	20	—	700	—	—	—	12,000	—	—	360,000

† This is probably much overrated.

\* De la Beche's Report, *ante cit.* p. 590.

miners for this ore :—it is extremely valuable, and, as well as the black ore (an almost pure oxide and containing nearly 80 per cent. of copper), is occasionally in sufficient abundance to increase very greatly the value of the produce of the mine in which it appears.

Even so lately as at the end of the last century many of these rich ores were thrown away by the miners, their value not being known, and before the year 1700 copper ore seems to have been only obtained accidentally, and from mines worked for tin.

The ores having been thrown into the places appointed for them, are broken by small hammers and divided into two heaps, one containing the good ore, and the other what are called *leavings*. These fragments are then passed through the crushing machines, in which the ore is crushed to the size required for carrying on the farther processes between iron or steel rollers, generally set in motion by water-power. As the crushed ore falls from the rollers it is received in a sieve, commonly inclined and made cylindrical, so that by turning round on its axis the larger pieces of ore slide down to the bottom, while the smaller pass through the wires of the sieve, and by these means the fragments which have not been sufficiently crushed are collected, and may be passed again through the rollers.

The next process is called *jigging*, and is accomplished by putting the crushed ore into a rectangular chest, or tub, in which a sieve is suspended and immersed to a proper height in water. To this sieve a vibratory motion is communicated, so that the particles in it arrange themselves according to their relative specific gravities; the metallic particles being the heaviest are thus carried to the lower part of the sieve, and the rest may be removed, and if thought sufficiently rich, be *jigged* over again. The richer

portions are then picked out by hand, a work performed by women and children, and the poorer parts are passed to the stamping-machine, where, after being pounded, the metallic portions are separated, still by the aid of the water, from the other parts.

By the processes of picking, crushing in various manners, jigging, and washing, the ore is at length rendered saleable, and it is then usually exported to Swansea in South Wales, there to be smelted with the copper ores from other parts of the United Kingdom, and from many foreign countries, taken to the same place. In the year 1838 nearly two hundred thousand tons of copper ore were there smelted.

The quantity of copper ore raised in Cornwall is very considerable, and has been steadily increasing on the average of a number of years. In 1775, the quantity did not amount to 3600 tons, and its value was 192,000*l*. At the commencement of the present century it had increased to upwards of 5000 tons, and its value then was nearly half a million of pounds sterling. A quarter of a century later the supply was upwards of 8000 tons, and its value reached 750,000*l*., while in 1838, 11,527 tons of copper, obtained from 145,688 tons of ore, were raised, and the value of the metal was 857,779*l*. Of the Cornish mines, the Consolidated mines are those from which the greatest amount of profit is obtained from copper mining. In addition to the quantities mentioned above, about six thousand tons of ore, producing 527 tons of metal, were raised from the Devonshire mines in 1838.

The ore from which is derived nearly, if not quite, all the tin obtained from the Cornish mines, is the per-oxide, and it occurs of variable degrees of purity, sometimes crystalline and at others mixed with much earthy matter. Except when mixed with *wolfram* (the tungstate of iron and

manganese) it is readily separable from earthy impurities owing to its great specific gravity, but the presence of wolfram not allowing this process to be used, is considered highly injurious to a tin-lode.

The mechanical act of separating the tin ore from minerals associated with it (technically called *vanning*) is effected with great dexterity by the Cornish miners. It is done by placing a small portion of pulverised ore towards the end of a pointed shovel, and then, by dexterously dipping it in the water and agitating it by a peculiar motion of the arms and wrists, it arranges itself according to the relative specific gravity of its component parts.

But the operation of *vanning* is subsequent to the first processes that are gone through after the ore is obtained from the matrix or separated from the gravel amongst which it is found. The ore, however obtained, is carried first of all to the stamping-mill (usually worked by steam-power) to be crushed and pulverised under water. It is then carried, mechanically suspended in running water, into a pit, where, arranging itself according to its specific gravity, the heaviest part is accumulated at the head. The more slimy ore passing to the lower end, a further deposit is made in a round pit at the end of the first or rectangular one, and the matter still remaining suspended in the water is allowed to be carried away as worthless. In this state the heavier mass in the first pits is called the *crop*, and the other the *slime*.

The ore being thus separated, the *crop* is taken to a large pit, termed a *buddle* (about 7 feet long,  $2\frac{1}{2}$  wide, by 2 deep), and a man standing in this pit arranges the pulverised ore upon an inclined wooden frame, in small ridges parallel to the run of some water which is allowed to enter the frame with regulated velocity. In this way, and by a few simple contrivances, the ore is divided into four heaps, which differ-

ing in the rate at which they sink, differ in the same way in relative value. After this, the heavier portions are again subjected to a similar washing in a large vat, and of the rest, all but the lightest are *buddled* once more, or are at once separated as leavings. The method of separation is in all cases the same, the greater specific gravity of the ore being the only means employed to separate those which are metallic from the mere earthy particles.

After various operations of this kind,\* and when the ore has been exposed to washing till but little earthy matter remains, it is usually roasted in furnaces, which contain about seven cwt. of ore, and while undergoing this process is stirred about until it ceases to exhibit bright sparks or emit whitish fumes. In this way it is freed from various impurities, such as arsenic, sulphuret of copper, common iron pyrites, &c., which are driven off in the state of vapour, and it is afterwards again washed and sifted, and reduced to the state called black tin, in which it is saleable, and contains a very large per centage of pure metal. The total annual produce of the Cornish mines varies considerably, but it may perhaps average about seven thousand tons of black tin, the value of which is something more than 350,000*l*. The further processes by which it is reduced to the metallic state and afterwards refined, belong strictly to the art of metallurgy, and although not entirely excluded from considerations of practical Geology, hardly admit of description in the limited space I am enabled to devote to the subject.

\* The ores of copper and tin, of which the method of treatment has been in some measure described, belong to that class which may be called *disseminated* (in German, *eingesprengt*) and in both cases the metalliferous particles

\* These are minutely described in Sir H. de la Beche's Report, p. 577.



being comparatively small, they can be prepared for smelting merely by stamping (or pounding) and washing; the metalliferous particles being heavier, and separating themselves from the other minerals by the proper application of a current of water. It will, however, readily be understood that the shape of the particles may have a considerable influence on the applicability of this process, and in fact it is only when the metallic ore occurs, more or less, in the form of grains, that the separation by washing is advantageous, while, on the other hand, when it exists in the shape of thin leafy or scale-like particles, these metallic particles, instead of sinking more rapidly, float longer than the non-metallic substances with which they are mixed.

The principal lead ores in England are those worked in the north of Derbyshire, in the county of Flintshire in North Wales, and in the neighbourhood of Alston Moor in Cumberland, and the veins containing the ore have been already alluded to as offering some singular and interesting peculiarities of form. From these veins the ore of lead called *galena* (a rich sulphuret) and ores of zinc (*calamine* and *blende*) are obtained in considerable abundance, and the lead is usually accompanied by a small per centage of silver, varying from two to about four-and-twenty ounces per ton.

The *galena* is principally cubical, but sometimes compact, steel-grained, and accompanied by ores of antimony, and these two ores are frequently blended together and intimately mixed with the spar or vein-stone, locally called *rider*. Another ore of lead also occurs, not crystalline, but in plates presenting a smooth surface, and usually adhering to sulphate of barytes: it is called *slickensides*,\* and the sulphate of barytes to which it is attached possesses the pecu-

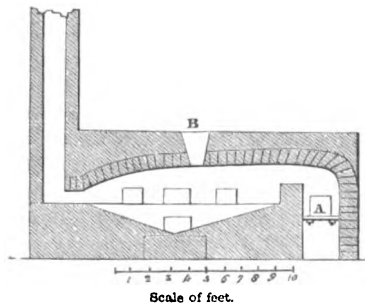
\* The smooth striated surface of a fault is also in some cases designated by this name.

liar property of spontaneous explosion when first laid bare. The explosion usually takes place ten or fifteen minutes after a small incision or cavity is made with the point of the pick, and considerable masses of ore and vein-stone are often detached by it.

In Derbyshire and the north of England, as in Cornwall, the working of mines is subject to special laws, mostly of very ancient date, but in the northern district these laws only apply to a part, and even a small part of the whole mining country, that namely, which is known as "the king's field," in the north of Derbyshire.

The ores of lead often occur in pieces so large that they do not require to be separated from the veinstone by the processes of stamping and washing; they are then called *pure ores*, and the most simple preparation is sufficient to prepare them for the smelting-furnace. When the ore has been picked and so far prepared, it is first roasted or heated in a reverberatory furnace,\* and in this way the sulphur

\* A reverberatory furnace (see the annexed diagram) is a furnace in which intense heat is produced by a flame which, while passing through the furnace, *reverberates* from the roof over the substance to be fused, the draught being created



SECTION OF A REVERBERATORY FURNACE.

by means of a lofty chimney. The form commonly used in roasting the lead and other ores of Derbyshire, is shewn in the accompanying diagram, where A represents the fire-place, and the flame is forced to pass round over the hearth be-

is partially expelled, and the ore rendered more easily reducible.

The lead which remains after the operation of roasting is in an oxidated state, and is then mixed with the necessary quantity of coke, charcoal, or peat, and reduced by smelting in a small blast-furnace of a peculiar kind. By the application of heat and the inflammable matter with which it is mixed the metallic oxide is decomposed, and the oxygen, combining with the carbon, flies off in the form of carbonic acid gas, while the lead is reduced to the metallic state, and sinks to the bottom of the furnace. The produce from the finer ores amounts to 70 or 80 per cent.

Almost all the varieties of galena, or lead-glance, contain a greater or less proportion of silver,\* and it is often found worth while to separate the silver by taking advantage of the difference of oxidability of the two metals. This is done by exposing the argentiferous lead to a strong blast of air, at a high temperature, in a furnace so contrived as to allow the litharge, (protoxide of lead), to separate immediately, while a fresh supply of lead is constantly introduced as the operation proceeds. The lead thus becomes rapidly

fore proceeding to the chimney. In a *blast-furnace* the fire is maintained by an artificial stream of compressed air, and the fuel is brought into immediate contact with the substance to be acted upon.

\* The Cornish ores contain a larger proportion of silver than those of Derbyshire and the north of England, but the method of treatment is the same, or very nearly so. In one mine, near Truro, as much as one hundred ounces of silver per ton of lead was obtained in 1720, and this mine was re-opened in 1814, and then yielded at the rate of seventy ounces. But the Beer Alston mines in Devonshire are the most remarkable for their riches in this respect; and the two lodes near Beer Alston have produced large quantities of argentiferous galena, often containing from eighty to one hundred and twenty ounces of silver per ton of lead. According to Mr. Hitchings, the greatest proportion which occurred in any one part was one hundred and forty ounces. Independently of these argentiferous ores of lead, native silver, ruby and grey silver ores, and the black sulphuret, have been raised from various mines in Cornwall. Gold is also occasionally found; but this is in the tin stream-works.

converted into the protoxide (litharge), while the silver forms a cake, readily separated at the end of the process. The litharge is reduced to the metallic state again in a reverberatory furnace, and the total loss does not amount to more than about one sixteenth part of the original quantity of metal.

Next to lead, zinc must be considered as the most important metal obtained from the Derbyshire mines, and the discovery that this metal is malleable at a temperature of 300° Fahrenheit, and can then be worked to any shape with great facility, has caused it to replace lead for many purposes, in which its hardness and other useful qualities render it superior. The ores of zinc commonly worked are two, *blende* (the *black jack* of the English miners) and *calamine*, the latter of which has long been known as an important constituent of brass.

Blende is a sulphuret of zinc, and, together with calamine, is found associated with lead ore in the veins of the mountain limestone of Derbyshire, and Alston Moor. The latter ore (calamine) is also found in the magnesian limestone, and has been worked in the Mendip Hills, near Bristol, from a considerable number of small excavations, the ores consisting partly of galena, and being mixed also with a considerable proportion of carbonate of lime. In the north of England the ores of zinc sometimes accompany lead ores in the same veins, but they are also met with in separate veins, while in one instance of a rich vein of lead, worked at Holywell, in Flintshire, calamine is found only in the east and west ramifications of the vein (whose principal direction is north and south), while blende abounds in the mine, and occurs indifferently in all parts of it.

The ores of zinc, like those of lead, after being coarsely

pounded, are usually calcined in reverberatory furnaces, but are sometimes burnt without undergoing this process. In the latter case the ore is first broken into fragments about the size of a pigeon's egg, and is mixed with an equal quantity of coal.

In reducing the calcined ores of zinc to the metallic state, rectangular or round furnaces, containing a number of crucibles, are commonly employed. The crucibles themselves are made of clay, and are pierced at the bottom with a hole plugged with a piece of wood, the carbon of which assists the running of the metal when the fire is applied. The crucibles containing the ore are introduced at the side of the furnace through apertures, which are afterwards filled up with fire-brick. For about two hours the crucibles are left in this state and without any cover, but then, when the appearance of a blue flame indicates that the reduction of the metal has commenced, the covers are put on, and vessels, called condensers, are placed to receive the metal. The sole care of the workmen now is to keep the fire active, and remove the condensers when they are full, replacing them by others.

The fire is not allowed to diminish, but successive charges of ore replace those from which the metal has been obtained, and the operation goes on continuously.

The zinc is obtained in the form of small drops or grains, or fine powder, mingled with an oxide of the metal. This is melted afterwards in an iron cauldron, and run into moulds.

Manganese is a metal the consumption of which has very much increased of late years, and its ores must now be considered to form an important part of the mineral riches of our country. The value of the manganese exported from Cornwall in 1837, amounted to 40,000*l.*, and

a very considerable portion of the whole quantity is employed in the manufacture of the chloride of lime, the solution of which is used as a bleaching liquid. The mines from which manganese ore (chiefly the grey or black oxide) is obtained, are mostly shallow, and sometimes even worked at the surface, and there is probably no instance in which any important machinery is required, or indeed, anything more than a horsewhim to be employed in raising the ore. The metal itself not being made use of in the arts, there is no need that I should detain the reader with an account of the difficult processes by which the chemist is enabled to reduce it. Besides being found in great abundance in Cornwall, the grey oxide of manganese occurs in all parts of Europe and in America, and is usually associated with iron ores.

The ores of many other metals are found occasionally in the metalliferous veins of Great Britain, and amongst them may be mentioned cobalt, bismuth, nickel,\* and arsenic, all occurring in Cornwall, and generally accompanying the ores of copper, but none of them very abundant. Antimony is much less rare, and occurs in the native state, accompanying lead, and combined in definite proportions with sulphur. Iron is everywhere distributed, and very rich *hæmatite*, and some other ores of iron, occupy an enormously thick vein which traverses the mountain limestone at Ulverstone, in Lancashire, and veins of smaller importance in Cumberland and Devonshire. But the ores of iron, which from their abundance, and from the circumstances of their occurring associated with coal and

\* It is a singular fact, that nickel is usually associated with iron in those *meteoric stones*, as they are called, which are found occasionally in all parts of the earth. Enormous masses of iron, combined with nickel, are also found scattered over the surface of the ground in Mexico.

limestone, are of the greatest economical importance, and supply almost the whole of that vast quantity annually consumed in England, are not deposited in veins but are regularly bedded, and will come under our notice in another chapter.

It is not necessary that I should detain the reader here with any detailed account of the methods employed on the Continent of Europe in obtaining those metals found abundantly in our own island. The different mining districts of Germany, indeed, and more especially Saxony and the Hartz, have for ages been celebrated for the extent, and the perfection of economic arrangement, with which their mining operations have been carried on, but the methods employed do not differ sufficiently from those already detailed, to admit of any popular statement. Much of the manipulation in metallurgy must depend on the tact and quickness with which the manager of a mining property can avail himself of the constantly varying circumstances of the ore and the mineral vein he is working; and a due or improper admixture of ores may often make the difference between success and failure.

Such knowledge as this can only be the result of experience, and is not to be attained without careful attention and minute observation; but although a familiar acquaintance with the principles of Geology must be extremely valuable even to the metallurgist, it would be unreasonable to expect in a general account of Geological facts any detailed information on a subject so technical.

Of the metalliferous ores not found so abundantly in England as to be worth working on their own account, the chief are those of silver and gold, which at present are principally obtained from the Continent of America and from Asiatic Russia; and those of mercury, long worked,

and still very abundantly found in Spain, and also in the mines of Idria, in Carinthia.

Of the precious metals, I have already mentioned silver as occurring in our own country to some extent, but until the discovery of America, a very large proportion of the whole supply of Europe was obtained from the celebrated mines of Saxony. Russia has always contributed a considerable amount of gold, and also a large quantity of silver, and there can be no doubt that both metals have found their way to Europe from various parts of Asia, where, more especially in the East, they appear to be sufficiently abundant.

In describing the methods of obtaining silver, I shall chiefly allude to those pursued in the celebrated Mexican and Peruvian mines, and it ought to be distinctly understood that, notwithstanding the very large quantity of the precious metals obtained from the mining districts of South America, the ores are not on the average richer than those of Freiberg, of Hungary, or of Transylvania.

It is not, therefore, (as is generally supposed,) from the intrinsic value of the minerals, but rather from their great abundance and the facility of working them, that the mines of America are to be distinguished from those of Europe; the mean wealth, even of the richer veins, not being greater than four ounces of silver to the hundred-weight of ore extracted, while many districts of Saxony have, at fortunate periods, yielded ten and even fifteen ounces, and have seldom averaged much below three.

The mines of New Spain, the central group of which comprise three mining districts, including an area of about seventeen hundred square leagues, are probably the most abundantly supplied with the precious metals of any in the world, and of the three districts, the most southern



of the group—that of Guanaxuato—is as remarkable for the gigantic labours of man in the bowels of the mountains, as for its vast natural wealth.

A group of porphyritic hills, partly arid, and partly covered with the evergreen oak and the strawberry tree, rises on the ridge of one of the mountains of the Cordilleras, from a part of the great central table-land of Mexico. The absolute height of the summits of these mountains ranges from 9000 to 9500 feet above the sea-level, but as the neighbouring plain is nearly 6000 feet above the sea, they appear only as insignificant hills to the eye of the traveller accustomed to the lofty mountains of the Southern Continent. The famous vein of Guanaxuato, the *veta madre*, crosses the southern slope of this porphyritic range, and the outcrop of the vein runs from south-east to north-west.

The quantity of the precious metals obtained annually from this vein on the average of a number of years, amounts to nearly *three hundred thousand pounds weight of silver, and eight hundred pounds of gold*, nearly double the average of the more celebrated mines of Potosi.\*

This vein it has already been stated, has been worked for a length of upwards of six miles, although the silver has been extracted only on a line of about one mile and a half. Its direction is stated by Humboldt to be N. 52° W.,† and its inclination from the vertical 45° or 48° to the south-west. It has been doubted whether this great mass of metalliferous ore could properly be called a vein, as it seems to have the same direction and dip as the

\* The mountain of Potosi has, however, furnished since its discovery in 1545 to the beginning of the present century, *at least* as much silver as was worth 235 millions of pounds sterling, although at the present day the quantity extracted is comparatively very small, and the proportion of metal only about 1 in 2500.

† Political Essay, *ante cit.* vol. iii. p. 185.

clay-slate in which it occurs; but in spite of this remarkable coincidence of direction of the crevice and the rock fractured, it appears to be a true vein, since towards the south it is known to run through porphyritic mountains, and throughout that part which has been worked its richness is found to be invariably greatest where the direction of the numerous ravines of the valleys which it crosses, and of the slope of the mountains, has been parallel to that of the veins.

It is found also to divide into branches, to vary very greatly and capriciously in thickness, and to contain *druses* abounding with amethyst and other crystals. There seems to be a certain moderate depth at which the greatest riches occur, and this is stated by Humboldt to be between six and seven thousand feet above the level of the sea.

The mechanical contrivances resorted to, and the methods of working these mines generally, were at an extremely low ebb at the commencement of the present century, and although the ores are incredibly abundant, they are at the same time so poor, as not to average more than four ounces of silver per cwt. of ore. Notwithstanding this, the whole of the ore, at the period alluded to, was conveyed to the surface by human labour, the native Indians carrying a weight of from 240 to 380lbs., exposed to a temperature of from 70° to 80° Fah. for a space of six hours, and during this time ascending and descending several thousands of steps in pits having an inclination of 45°. The works too, at that time, rarely communicated with one another, the drainage was in the worst possible state, and was effected by mules, who raised the water in bags, while a considerable proportion of the water was allowed to drain from the upper works to the deepest part of the mine.

Nor was the miner better informed or more economical in his work. The quantity of powder used in blasting was much more than necessary, and all the arrangements seem to have been conducted in the most careless and uneconomical manner. Doubtless all these matters have been greatly improved within the last quarter of a century, and the works are now conducted with care and attention, and with economy, but no general account of the improvements has yet been recorded, nor is it very likely that another Humboldt will soon be found to narrate with accurate minuteness the details of all the important works now proceeding in this interesting district.

The methods of preparing the ores of silver and gold differ according to the process by which it is intended to obtain the metal. A considerable proportion of the ore is destined for the process of amalgamation, and in this case it is triturated in powerful mills (generally in a crude or raw state, sometimes dried, and sometimes, though rarely, roasted in large heaps out of doors). After undergoing trituration, which is effected if possible by means of hydraulic wheels, but more usually by mules, the ore is sifted through a hide sieve, and the coarser parts are returned to be again stamped, while the finer portions are reduced to a very fine powder under blocks of hard stone, dragged round horizontally in a circular pit. A great number of these mills are attached to works of any importance, and even the smaller ones are provided with twelve or fifteen of them ranged in a row, and each grinding from ten to twelve cwt. of ore daily. A small quantity of quicksilver is added to such silver ores as have traces of gold, because mercury having a greater affinity for gold than silver, a fluid auriferous amalgam is thus obtained which contains but little silver.

The amalgamation generally takes place in a yard care-

fully paved and well enclosed by substantial walls. In this yard the heaps of ore to be amalgamated are thrown, each heap containing from fifteen to thirty-five cwt., and forty or fifty such being exposed to the open air in a damp state.

The heaps are then prepared by mixing with them about six per cent. of salt as soon as they have received due consistency, and after this mixture they are left undisturbed for a few days; then follows the admixture of metallic salts, technically called, "magistral" (*regulus*). Various mixtures are made use of for this purpose, the oxides and sulphurets of copper and iron being the chief elements. Formerly, gently roasted copper pyrites, either with or without iron, and muriate of soda, were alone made use of, but of late years a protoxide of copper has been introduced, and is found advantageous. The quantity of this magistral to be mixed with the ores differs greatly according to their quality, some needing six per cent. while others require only one. It is first strewed on the heap, and soon afterwards the first portion of quicksilver is added, being sprinkled on by passing it through a linen cloth. It is then triturated with very great care from time to time, much attention being paid to the due consistency of the paste, and continued examination being made, to see whether the incorporation, which consists in simultaneous oxidation, formation of chloride, and attraction of the silver by the mercury, is duly going on. If it be too lively, it can be checked by the addition of lime, and if too tardy, a further addition of *magistral* will quicken it.

The process lasts a very variable time, depending partly on the climate and partly on the nature of the ores, so that sometimes it requires not more than three weeks, and sometimes as much as two months. About six pounds weight

of quicksilver is allowed for each pound of silver expected, and the loss of mercury is very considerable, amounting to about one and a half times the weight of the silver obtained. The amalgam is reduced and the silver separated by the process of distillation.\*

The quantity of silver produced from the Mexican mines in 110 years, ending with the first year of the present century, was something more than ninety-eight millions of pounds troy, and the total value of the gold and silver together, produced from 1689 to 1803, has been calculated at about 285 millions of pounds sterling. Since the commencement of the present century the quantity has been increasing, though not with any regularity.

Before concluding my remarks on the precious metals, I must not omit to mention the greatly increasing importance of the Russian provinces of Siberia, with respect to gold ores. During the past fifteen years the supply of gold from that country has been gradually, but steadily and

\* The process of amalgamation is carried on in Saxony in a manner somewhat different from that described above. It is found that the amalgamation succeeds best when the proportion of silver is about seventy-five ounces in the ton; and the ores are therefore selected so as to bring the whole as near this average as possible, regard, however, being had to the proportion of sulphur, which is ascertained by assaying the ore. As the combination with sulphur, and other substances, interferes with the amalgamation, the raw ore is first mixed with 10 per cent. of common salt, and being then burnt, the sulphur becomes acidified in the furnace, the liberated acid combines with the base of the salt, forming sulphate of soda, and muriate of silver is formed by the union of the muriatic acid of the salt with that amount of silver in the ore not already in the metallic state.

In this state the ore is reduced to an impalpable powder, and submitted to the action of mercury in barrels, which are so arranged as to revolve on their axes. The charge in each barrel consists of calcined ore, mercury, metallic iron, and water in certain proportions, and by constant friction during sixteen or eighteen hours the muriate of silver is decomposed by the iron, the silver combining with the mercury, while the sulphate of soda, muriate of iron, and other salts, are dissolved in the water. The result is then filtered, and the amalgam subjected to the action of heat, which drives off the mercury, the silver remaining.—Taylor's Records of Mining, p. 31.

rapidly, increasing, so that while in 1830 the value of the metal obtained did not amount to 10,000*l.*, in 1842 upwards of 30,000 pounds weight (troy) was obtained, the value of which would be nearly a million and a quarter of pounds sterling, and it is believed that the quantity was even greater in 1843. The greater part of this large supply is derived from washing the auriferous sands.

Platina is a very remarkable metal, usually associated with gold in the mines of Russia and South America, and only found in the native state. It is the heaviest, the most difficult of fusion, the most ductile, and the most flexible metal. It occurs in small flat shining grains, and its colour is a light steel grey, approaching to that of silver, whence its name is derived (*Plata*, silver). It is extremely malleable, and like gold is only affected by nitro-muriatic acid. It welds like iron, and in this way is capable of being manufactured into cups, crucibles, and spoons for chemical purposes, and small reflectors, for all which its peculiar qualities admirably adapt it.

The chief source of the supply of Mercury is the extensive mine of Almaden, in Spain, which has been worked for upwards of two thousand years. Besides this, the mines of Idria have been resorted to from time to time, but there can be little doubt, from indications that have already appeared, that the importation of this metal from Europe will soon be quite unnecessary, and Mexico and Peru, instead of being dependant on the Old World for this metal, will soon be in a condition to supply it. The existence of veins containing ores of quicksilver has indeed long been known in South America, and one very remarkable mine, that of Huancavelica, is worked at the height of 14,500 feet above the sea, the ore obtained being a rich cinnabar, (sulphuret of mercury,) and apparently existing in great abundance.

The mines of Idria are scarcely less celebrated than those of Spain for the ores of mercury they contain, but the produce is by no means so valuable. Cinnabar is there also the principal ore, and it is distributed in various ways through the matrix, sometimes nearly pure and in small fragments, and sometimes appearing as a compact mineral of a deep red colour.

Native mercury is found occasionally disseminated in the veinstone both there and in one or two mines of cinnabar, near Obermoschel, in Rhenish Bavaria, not very far from the town of Bingen on the Rhine. These latter mines are also interesting as frequently containing good crystals of a native amalgam of mercury and silver.

The usual method of reducing the ores of quicksilver is by distillation. The minerals brought out of the mine are broken up, and picked by women and children, and then in some places the richer ores are separately burnt, but it is more usual, and considered more economical, to mix the richer with the poorer ores, and expose the whole mass together to the action of heat in closed retorts, which also contain a certain proportion of limestone.

The retorts, filled with the mixture of ore and limestone, are ranged to the number of twenty or more in recesses of a furnace, and heat being applied, each retort is made to communicate with a vessel of water, in which the vapours of the mercury are condensed. In the mines of Idria a different method is adopted, the ores being there roasted in a kind of oven, and the vapour resulting from this operation passing into condensers, where the little drops of mercury collect, and are conducted into a porphyry vessel placed to receive them.

Besides those which I have now described, and which are the metals chiefly used in the arts, there are a number of others, some of them valuable when mixed with other

metals but of themselves rarely employed, while others are only known by their salts and oxides, and others again have not yet been applied to any practical use, and are only objects of interest to the chemist.

Bismuth, Nickel, Antimony, and Arsenic are among the first of these metals. The next includes Sodium, Potassium, Calcium, Chromium, Cobalt and some others; while Rhodium, Iridium, Osmium, Palladium, Yttrium, Tungsten, Titanium, &c., complete the list.

Bismuth is generally found native in veins of silver or cobalt ore, and it is readily obtained from these ores by processes in which advantage is taken of its extreme fusibility. It forms alloys with other metals.

Nickel is a somewhat interesting metal, being always present in what are called "meteoric stones," and becoming readily magnetic. It is usually mixed with arsenic in veins of lead and zinc. Nickel is an exceedingly brittle metal.

Antimony, in the condition of a sulphuret, is found very frequently associated with the ores of lead, and is a metal of considerable importance, being used in the arts to some extent, especially in the manufacture of type-metal. It is also used in medicine.

Arsenic is a metal of very frequent occurrence, and is found both pure, and in combination with other metals. Its presence may be known by the odour of garlic which it gives out when heated or struck with a hammer.

With regard to the other metals. Cobalt is never found pure, but is mostly combined with arsenic and sulphur. Chrome, like cobalt, is best known as a pigment, communicating a green colour to porcelain, &c. Calcium, sodium, and potassium are the metallic bases of lime, soda, and potass, and are never found native. Rhodium, iridium, osmium, and palladium are extremely rare, and are only found alloying platina.



## CHAPTER VI.

ON THE METHODS OF OBTAINING MINERAL PRODUCE FROM BEDS INTERSTRATIFIED WITH THE REGULAR DEPOSITS WHICH FORM THE GREATER PART OF THE CRUST OF THE GLOBE.—MINING FOR COAL.

THOSE departments of mining which have been considered in the preceding chapters, have reference only to the metallic ores obtained from lodes or veins in fractured strata, the fissures so filled up being due to the action of subterraneous violence subsequent to the deposit of the strata. Such ores differ in this respect entirely from minerals which are regularly bedded, and which themselves interstratify with the limestones, the clays, and the sandstones, and help to make up the great series of rock formations; and it will be found that this difference extends to the contrivances that are necessary in order to obtain the bedded minerals from the bowels of the earth.

It results from the simple fact that the minerals in one case are bedded, and in the other are deposited in crevices in the fractured strata, that there should be a regularity existing in the former, and a uniformity of general character and appearance utterly unknown in the latter, and it cannot excite astonishment that the methods of underground working in the two cases differ most essentially. As, therefore, in the former chapters I have described at some length

the successive processes by which metalliferous ores are extracted from mineral veins, brought to the surface of the earth, and there reduced to the metallic state, so now I shall speak of mines of another kind, from which minerals are obtained, (chiefly coal and iron,) which form actual beds, and an integral part of the crust of the earth.

Nor are these minerals, of which I am about to speak, namely, coal and the ores of iron, to be considered of inferior importance among the mineral produce of England. If, indeed, the British Islands occupy, as they do, a most important place among mining countries for the value and extent of their mines of copper, tin, and lead, they are far more distinguished from the rest of the world by their unequalled riches in the more useful, if not more intrinsically valuable supplies which they contain of coal and iron ore. Notwithstanding the cheapness of the produce of this kind, the value of the coal actually brought to the surface in England amounts annually to nearly ten millions of pounds sterling, and almost the whole of this is derived, although in unequal proportions, from the Newcastle, the South Welsh, the Staffordshire, and the Scotch coal-fields.

With regard to the first of these, the Newcastle coal-field, it is said that upwards of six millions of tons are there annually raised up out of the bowels of the earth, that 60,000 persons are employed in the mining operations, that fourteen hundred vessels are constantly engaged in conveying the coal (amounting to three millions of tons) required for the consumption of the metropolis only, and that the capital involved in simply conducting this trade amounts to several millions of pounds sterling.

On the other hand, in the South Welsh and the ad-

joining coal-basins, the coal is chiefly used in the manufacture of iron, and the smelting of copper and other metals. In 1839, more than half a million of tons of pig iron were made in the Forest of Dean, and nearly three hundred and fifty thousand tons in South Staffordshire. In the manufacture of this quantity, at least five millions of tons of coal were required, and another million of tons were during the same year exported.

Compared with these numbers, the quantity of coal raised from the other fields will appear inconsiderable, but certainly not less than three millions of tons more are extracted from the mines in Scotland, from those distributed in various parts of England not before included, and from those in Ireland.

We see, then, that at least fifteen millions of tons of coal are annually extracted from coal-mines in the British Islands, and are employed for the use of man. I regret to be obliged to add, that a quantity, supposed to amount to, *at least*, two millions of tons more, is during the same short period wantonly destroyed, in order to enhance the price of part of the remainder.

It is not my intention to discuss in this place the validity of the arguments that have been advanced in proof of the vegetable origin of coal. Something has been said on this subject, in treating of the fossils of the carboniferous system (vol. i. p. 346), and perhaps enough to convince the unprejudiced reader; for if the actual discovery of organised structure and of vegetable tissue in the coal is not sufficient proof of its vegetable origin, it would not be easy to say what greater amount of evidence would produce conviction. But the condition of the vegetables, and the kind of vegetation imbedded, must still be considered as doubtful questions, and it is not unlikely that

in different localities, all the different modes that have been suggested may at some time or other have been brought into action.

There are, however, two exceedingly important matters to be considered and understood before proceeding to the practical question of the method of working in coal-mines, and these matters themselves are both eminently practical, both strictly dependant on that class of phenomena studied by the Geologist, and both, therefore, proper to be discussed in this place, as connected with the Geology of practical mining. I allude to the frequent repetition, and as frequent loss, of the coal strata, by faults and dislocations, and to the fact, that those beds containing valuable fuel capable of being extracted and employed for economical purposes, are only found in one formation, are even strictly confined to a certain part of that formation, so far as practical mining is concerned, and are confined to that formation, not only in our own country, but wherever extensive deposits of coal have hitherto been found in Europe.\*

This latter fact is one, the knowledge of which is

\* This is at least strictly true so far as regards bituminised vegetable matter developed to any extent in Europe, and capable of being used for economical purposes as fuel. Doubtless the lignites and imperfect coal worked at Brora, in the lower, and at Kimmeridge, in the upper oolitic strata, and the brown coal of Germany and Switzerland are capable of being burnt, but they do not form true coal; and perhaps the most remarkable fact is, that these different beds exhibit scarcely any approach to the nature of true coal, so that it appears as if there really is scarcely a possibility that they ever could become so. By far the largest and most important deposits of lignite are those which have been somewhat extensively worked in the northern parts of the Duchy of Nassau; and here these tertiary beds, although they exhibit every external appearance belonging to regular carboniferous deposits, are so loaded with earthy matter, which is intimately mingled with their component structure, that they have not hitherto been made to give out a sufficient lasting heat to perform any of the important practical duties of fuel. Such is the case, also, with most of the tertiary and secondary lignites in other parts of the world.

obtained by experience only, and as to a certain extent it partakes of the indeterminate nature of all negative propositions, it may be considered as not yet sufficiently proved. But the evidence, if not complete, is at least exceedingly strong; and the degree of probability that coal, as a valuable mineral, is confined to the upper part of the Palæozoic series of deposits, is so great, as to be a safe guide in all the speculations of prudent men. It is not that other groups of strata have always been formed at a distance from land richly clothed with vegetation; for, on the contrary, some (as, for instance, the Wealden formations) are entirely of freshwater origin, while the carboniferous system is almost exclusively marine; and others, as the beds of the lower oolites, are associated with sandstone and shales, loaded with vegetable remains. Other accumulations, also of ancient vegetable matter, are found in other beds, and indications appear in several of them of sandstones and shales, very similar to those associated with the coal; but the coal itself is always absent, or worthless, and a search for it in any bed of the Secondary or Tertiary period, seems sure to result in disappointment and failure. The Geologist can only lay this fact before the practical miner as a rule of observation, but it is one of great importance, and it is an example in which a sufficient acquaintance with Geology may be the means of saving the expenditure of large sums of money, under circumstances where there was not from the first any reasonable prospect of success.

Numberless instances might be quoted of vain attempts that have been made to obtain coal in other rocks than those of the Newer Palæozoic period in Europe, and each experiment in succession has only served to strengthen the conviction that must exist in the mind of every ob-

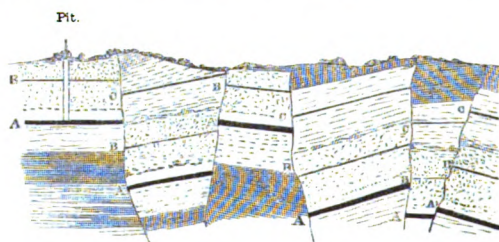
servant Geologist, that no exception is likely to occur to the general rule in this matter.\*

The other fact important to be duly considered by the practical miner, is that of the singularly frequent disturbances that have affected the beds of coal and the strata associated with them, and the remarkable complication of the *faults* that characterise every coal-field. It must not be supposed that the effect of these disturbances is either uniformly advantageous, or always disadvantageous to the immediate interests of the miner; but there cannot be the slightest doubt that we are indebted to such disturbances for frequent repetitions of the same bed of coal at the surface, when without them it would be so far covered up by newer deposits as to be utterly unattainable. If occasionally the miner, in prosecuting his labours, or the mine-owner in following what he considers a valuable seam of coal, is suddenly stopped by coming in contact with a fault, and finds the coal shifted several yards above or below, or even completely lost, he must not forget that it is perhaps owing to these very shifts that the outcrop has taken place at all in his neighbourhood, and that the coal is work-

\* Nevertheless this rule, although so universally applicable on the continent of Europe, may not apply in other parts of the world. I make this reservation, because the researches of Professor Rogers would seem to render it extremely probable that some of the thick beds of coal in eastern Virginia, in the United States of America, may belong not to the Palaeozoic, but to the Secondary period, and represent on a large scale the oolitic coal-field of Brora, the accumulations of vegetable matter at Scarborough, and the somewhat similar, and probably contemporaneous, beds at Cutch in the East Indies (see vol. i. p. 381). If this is the case, it will become an object of extreme interest to the Geologist to compare the unquestionably Palaeozoic coal-fields of America with these which are supposed to be of Secondary origin, and in which a characteristic coal-plant (*Stigmaria*) does not at all appear. See the Memoir by Professor W. B. Rogers, in the Transactions of the Association of American Geologists and Naturalists. Philadelphia, 1843, p. 298, *et seq.*

able throughout a very large proportion of the district in which he is interested.

I have already (vol. i. p. 36) explained, by a simple illustration, the nature of the disturbances which would produce such systems of faults as are found in the carboniferous strata, and in now offering to the consideration



FAULTS IN COAL STRATA. AUCKLAND COAL DISTRICT, DUREAM.

A. Main coal.

B. Crow coal.

C. Yard coal.

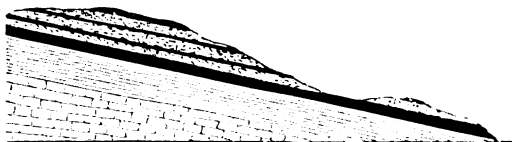
of the reader a section of an actual coal district, in which the faults, within a given space, are represented to a scale, I need only refer to the hypothetical sketch given in the first chapter of the Introductory part of this work, to shew how strictly analogous the two cases are.

But there is a most important advantage derived from the existence of these numerous faults in coal strata, namely, that they intersect a large field of coal in all directions, and by the clayey contents which fill up the crack accompanying the fault, become coffer-dams, which prevent the body of water accumulated in one part of the field from flowing into any opening which might be made in it from another.\* This separation of the coal-

\* An instance of the advantage resulting from the presence of a great line of fault, occurred in the year 1825 at Gosforth, near Newcastle, where a shaft was dug on the wet side of the great ninety-fathom dyke, which there intersects the coal-field. The workings were immediately inundated with water, and it was found necessary to abandon them. Another shaft, however, was sunk on the

field into small areas, is also important in case of fire, for in this way the combustion is prevented from spreading widely, and destroying, as it would otherwise do, the whole of the seam ignited.\*

The stratified condition of the coal, and the certainty of discovering the seam or bed in every part of a district known to contain carboniferous strata, would render the working for coal a mere mechanical labour, not requiring any special directions or any previous knowledge, were it not for the extreme abundance of faults, and the great influence they have upon the productiveness of a coal-field. But as a matter of fact, such previous knowledge, united with great experience, is exceedingly necessary, and requires to be founded on a familiar acquaintance with Geological phenomena.



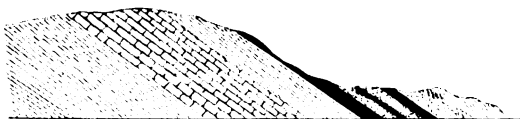
One of the most simple, though not the least important applications of Geological knowledge in mining, may be exemplified by considering the case of a coal-seam cropping

other side of the dyke only a few yards from the former, and in this they descended nearly two hundred fathoms without any impediment from the water.—Buckland's *Bridg. Treat.* vol. i. p. 544, note.

\* This is not so hypothetical an accident as might, perhaps, be thought. Many instances are on record of such fires having occurred, sometimes spontaneously from the decomposition of iron pyrites in contact with moisture, sometimes from lightning, and sometimes wilfully, in consequence of quarrels between the workmen and the coal-owners. When such fires do occur, they have been known to burn on slowly for many years, and within the last twenty years there has been more than one instance of extensive subterraneous fires, which have destroyed many acres of coal.



out in a valley, since there are no less than three very distinct cases that may occur, in each of which the method to be adopted in working the coal must be contrived with reference to the Geological position of the bed, and not only to the fact of the coal cropping out. The first of these is when the dip of the beds is less than the angle at which the valley slopes, both being in the same direction. Such is the case in the annexed diagram (p. 331), and it is obvious that a shaft sunk anywhere on the rise of the hill, will reach the coal, the seam of which may be worked safely and with little difficulty, the newer beds being always the highest in position. In the case represented in the subjoined diagram, however, where the dip of the bed is greater than the slope of the valley, and the direction is



still the same, it is obvious by observing the section, that there could be no useful result gained by sinking on the rise, above the spot where the coal has once been seen, the older beds coming out on the rise of the hill. It will be observed, that in both this case and the former the outcrop of the coal occurs at about the same height on the rise of the hill, and that the alteration of the dip of the strata is the only point of difference apparent.

The third case in which it is important to understand the Geological position of the coal strata is represented below, and occurs when the slope of the valley is in a different and nearly contrary direction to the dip of the beds. In this case the newest and not the oldest beds will necessarily appear the highest, and the coal may safely be looked

for at a certain calculated distance below the surface at any point of the section.



A due consideration of these differences in the mode of occurrence of the coal strata will be sufficient to convince the reader of the importance of attending to Geological conditions in mining operations of this kind, and will also shew the great value of those accurate maps and sections, now preparing for publication as the result of the Ordnance Geological survey. There can be no greater practical benefit to be expected from the study of Geology than the publication and general use of those maps and sections; and no one can fully appreciate them who does not look upon them with reference to this application, and to the certainty thence derived in mining operations of infinite importance to the commercial prosperity of England.\*

Having offered these preliminary observations, as to the circumstances of the occurrence of coal, let us next proceed to consider in what way, and under what conditions, the coal can be most conveniently extracted from

\* The nature of different kinds of valleys, an idea of which is attempted to be given in the above diagrams, is best understood by reference to models, where all the important points are at once seen. Such models have been prepared for sale by Mr. Sopwith, and they are also to be seen in the Museum of Economic Geology. The outcrop of the beds in a valley is often marked by a V-shaped line, and the direction and position of this V depend on the dip of the beds, the slope of the valley, and the nature of the denudation. In a valley of denudation where the beds are horizontal, the V will, of course, be so too; where the beds dip in the same direction as the slope of the valley, and their angle of inclination is less than that of the slope (as in the figure, p. 331), the point of the V will be upwards, while if the angle of dip is greater than that of the slope (fig. p. 332), the V will point downwards.

the bowels of the earth ; and these conditions, depending partly upon the nature of the coal itself, partly on the thickness of the beds, and partly on their depth below the surface at the place of working, and on the dip of the strata, it will be necessary to distinguish between the North of England coal-field, where the beds are of moderate thickness, exceedingly bituminous, and worked at great depths, and the carboniferous deposits in Yorkshire, Staffordshire, Warwickshire, and Wales, where they are often enormously thicker, contain far less gas, and can be conveniently obtained from depths much less considerable. The North of England, or Newcastle coal, being that chiefly made use of in England as a fuel, it will be convenient to bring it first under consideration.

A recent French author, M. Piot,\* has well remarked, that three persons travelling to Newcastle in different directions, would receive totally distinct impressions of the nature of the industrial occupations of the people.

One traveller, for instance, coming by the railroad from Carlisle would cross an agricultural district, and might hardly notice the fact that any commercial value attached to it, or that anything was capable of being exported, except, perhaps, the lime obtained by burning the mountain limestone of the district. Should his journey be made by night, he may have been struck by the appearance of flame vomited from the chimneys of the glass-houses near Newcastle, and those at Lemington, but a few coking ovens would present the only external indications of the real nature of the riches that abound in that part of England.

Another person travelling from London by the steam-

\* *Memoires sur l'exploitation des mines de houille aux environs de Newcastle-sur-Tyne. Annales des Mines, 1842.*

boat, would probably admire and wonder at the vast multitude of vessels engaged in the coasting-trade of Britain, and his attention, perhaps, would be mainly directed to the vessels engaged in that branch of trade he was about to investigate. But it would not be till his arrival at the mouth of the Tyne, that he could form a sufficient idea of the true commercial importance of the northern counties; nor, until he had observed the numerous and well-built vessels in that river, and had seen the coal raised from a vast depth below the sea-level, and deposited on board these vessels, and his enthusiasm had been kindled by the animated appearance of the port of Newcastle, would he fully feel his own littleness, and his inability even to comprehend, in all its detail, so vast a development of national industry.

But the third traveller coming from Birmingham, and who has traversed the series of coal formations which extend from the middle of England northwards, and which he would also cross in the county of Durham, would, beyond all doubt, have the best idea of the riches of the country. Throughout his route, he could not but have noticed that everything is sacrificed to the coal, and the great works going on underground, would be announced to him by the immense apparatus erected on the surface for the extraction of the mineral riches, and for the drainage and ventilation of the mines. He would have seen the innumerable tram-roads, and their long succession of waggons laden with coal. He would have asked the meaning of the numerous extensive towns, built of uniform habitations, visible at intervals along the road, and could hardly, perhaps, express his astonishment at learning that they were all the dwellings of the tens of thousands of pitmen.

But the impressions made on each of these three travellers must be united if one would acquire even a feeble and imperfect notion of the chief points of interest which the coal-mining district of the north of England offer for consideration.

The Newcastle coal-field is bounded on the north by the river Coquet, and on the south it extends nearly to the Tees. Its extreme length is thus about forty-eight miles, and its extreme breadth measures twenty-four miles, but its area cannot be calculated at more than 800 square miles. It is intersected by two navigable rivers, the Tyne and the Wear, on the former of which is situated the town of Newcastle, and on the latter the city of Durham. The whole field is divided unequally into two parts by a great fault crossing the district a little north of the Tyne, and throwing down the strata on the northern side (or raising them on the south) to a perpendicular distance of ninety fathoms. This principal fault is usually called the 'main dyke,' and there are besides many extensive faults and dykes throughout the district.

There are as many as forty distinct beds of coal in the Newcastle coal-fields, but eighteen of them only are sufficiently important to be considered workable. The most valuable is called the *High Main*, and is about two yards thick. The *Bensham seam* is the next in value, and is remarkable for its excellent quality, and for the enormous quantity of gas evolved from it in the mine. The *Hutton seam* is also much worked, and is of good quality; and the rest are variable.

No ironstone, and only a small quantity of iron ore of any kind is found associated with the coal in the Newcastle coal-fields.

When by the various methods already described, or by

previous knowledge of the district, the presence of coal is ascertained, the first operation to be undertaken before opening a coal-mine is usually that of *boring* to discover the most advantageous spot for sinking a shaft, and extracting the coal. This is often necessary, owing to the extreme complexity of the various systems of faults in the district, and the impossibility of otherwise determining with certainty the prospects of sinking.

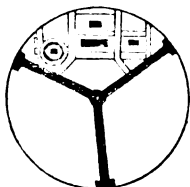
The operation of *boring* is generally effected with a kind of chisel, which being attached to an iron rod by means of a screw, and worked by a little temporary machinery erected on the surface, makes its way by alternate chopping and scooping, the accumulation of rubbish being taken out from time to time by an auger, as the chisel becomes clogged. Successive lengths of rod are screwed on as the work advances, and the nature of the strata gone through is determined with considerable facility and certainty by examining the fragments brought up by the auger. The expense of this operation varies, of course, greatly, according to circumstances; but through strata of moderate hardness the average cost per fathom may be stated at somewhere about 12s. within ten fathoms of the surface, and 6s. more per fathom after every five fathoms increase.\*

When in this way, or from previous knowledge of the district, it is decided where a shaft shall be sunk, this important work has next to be commenced.

The shafts in the north of England are usually cylindrical, or elliptical, and the smallest diameter is about ten

\* Thus, at 60 fathoms the cost would be (since the extra depth is 50 fathoms)  $12s. + 6s. \times 10 = 12 + 60 = 72s.$ , or £3. 12s. per fathom. This price must be understood as merely an approximation, and is often much higher; but whatever the nominal cost may be, rocks that are unexpected, and of great hardness, (such as porphyritic dykes,) are paid for extra.

feet. The smaller shafts are generally divided throughout into two compartments by an air-tight wall of separation (a *brattice*), but the larger ones, which have a diameter of as much as fifteen feet, are divided into three parts, and the section or horizontal plan of one of these shafts is represented in the annexed cut. One



SECTION OF THE SHAFT OF  
A COAL MINE.

of the compartments is made use of for drawing the coal to the surface, another for the drainage of the mine, and a third for ventilation, conveying to the surface the air that has passed through the workings.

Under the most favourable circumstances, the sinking a shaft is a work of considerable time and expense, for it is necessary to line almost the whole interior with bricks to prevent the loose and incoherent strata from falling, or being washed in; but it rarely happens that any depth of shaft can be sunk without meeting with springs of water, which sometimes empty themselves into the workings to an extent which it would at first appear hopeless to contend against. In such cases there is no safety to be obtained without lining, with a strong framework, that part of the shaft which passes through the loose permeable sands. This lining, of the shaft is called *tubbing*, and many pits around Newcastle and elsewhere, (where extreme durability is required, and no expense is spared to obtain this object,) were formerly lined throughout with three-inch boards nailed to a circular wooden framework, called a *crib*, which was firmly attached to the sides of the pit at convenient distances. But this method, although it has been known to keep out a pressure of water equal to 100 lbs. on the square inch, is not considered so safe as the

*metal tubing* now adopted in all difficult works. In some recent shafts as much as forty fathoms of a pit have been in this way completely lined with a strong cast-iron casing.

The depth of a shaft must, of course, vary indefinitely; but in the Newcastle coal-field it is rarely less than twenty-five fathoms, or 150 feet. The most common depth is, however, much greater than this, pits being sometimes sunk to nearly 300 fathoms (1800 feet,) and an expense of upwards of 50,000*l.* being often incurred before the seam of coal has been reached which it is intended to work.\*

It is usual in the deeper workings to have but few, or only one shaft, owing to the great expense of sinking; and it is the opinion of some of the most intelligent coal-viewers, that in this way, independent of all economical considerations, the deep workings are more conveniently and per-

\* The most remarkable and enterprising work of this kind on record is a sinking at Wearmouth colliery, near Sunderland, commenced in 1826, through the capping of magnesian limestone. The lower beds of the magnesian limestone and the lower new red sandstone here overlap the coal-measures, and at the place of sinking their thickness was known to be upwards of three hundred feet. At a depth of three hundred and thirty feet accordingly the coal strata were reached, but, at the same time, a spring was tapped, which poured water into the workings at the rate of three thousand gallons per minute. This fearful influx was kept under by a steam-engine of two hundred-horse power, and the work was made secure by strong metal tubing, and carried on successfully, though not without extreme difficulty.

On entering the coal-measures, however, a new and unexpected check was experienced. No calculation had been made for the extra thickness of the uppermost coal strata in those parts where the upper beds had been protected from denudation. This was found to require a much deeper sinking than had been expected; and the difficulties were increased when, at the depth of one thousand feet, a fresh *feeder*, or spring of water, was tapped. Additional expense and great loss of time was thus caused; but the proprietors persevered, and continued the sinking to the depth of 1578 feet, where they were rewarded by reaching a seam of considerable thickness and value. This was supposed to represent the *Bensham* seam, and they therefore resolved to continue the work in order, if possible, to reach the '*Hutton*,' the most valuable of all. The expense of this pit, including the necessary preliminary operations, could not have been less than £100,000, and at least ten years elapsed before any result was obtained.



fectly drained and ventilated, and that the general work of the mine goes on better.\*

It is rarely necessary in the coal-fields in the middle or west of England, or in Wales, to sink so deep for the coal, or undertake such costly works in order to obtain it; but the method of sinking is, of course, the same. In many places, however, it is found more convenient to sink a number of pits of smaller size than one large one, and in this way to avoid the extensive underground operations required in the north to effect the ventilation of such mines as have only a single shaft. The thickness of the coal in Staffordshire also renders it expedient to resort to methods of working on a principle somewhat different to that followed in the Newcastle coal-field, and these methods will require to be spoken of separately.

The shaft being sunk, it is usual to drive two galleries or levels, the one along a horizontal line on the strike of the coal-seam, and the other at right-angles to this on the rise of the bed. The former is called the *drift*, or water-course, and has important reference to the drainage of the mine, and the latter is the *winning headway*, or main thoroughfare, through which the coal is conveyed to the shaft when extracted from the galleries afterwards cut. These two principal and preliminary cuttings are usually of considerable dimensions, (from nine to twelve feet wide, and six feet high,) admitting of the passage of loaded waggons and horses, and they are almost always provided with a tram or pair of rails. In the shallower

\* It must be confessed that this opinion seems hardly reasonable when the great extent of the underground works to be thus ventilated is taken into consideration. In some mines upwards of seventy miles of passages, more than a hundred fathoms below the surface of the earth, are only provided with one pit, not above twelve or fourteen feet in diameter, for ventilation, drawing coals, pumping water, and every operation necessary between the surface and the works.

mines, and where a second shaft is sunk, the new shaft opens at the extremity of the winning headway, and ventilation is at once established.



VENTILATION OF COAL-MINES. TWO SHAFTS.

The safe and economical working of coal-mines, more especially in the north of England, where the coal gives out a vast quantity of noxious gas, depends so intimately on the steps taken from the first to keep the works in a proper state of ventilation, that I shall make no apology for entering at considerable length on that subject. Mines are well known to be subject to certain special accidents, and of these, the occasional presence of air unfit for respiration, the falling in of the roof, the incursion of an unusual quantity of water, and many others, are common to all, and are perhaps scarcely greater, or more serious, than those accidents which are constantly recurring in other employments.

But in addition to these, and far greater than any of them, there is a cause of accident peculiar to coal-mines, and most peculiar to those of greatest economical value, those, namely, which supply the metropolis with its millions of tons of fuel, and which must and will be worked with every kind of energy, and in spite of every risk, so long as they continue to be a source of profit. The Newcastle coal is well known to abound with carburetted hydrogen gas, which it always gives off readily when exposed to heat, but which is also evolved sometimes slowly and insensibly, but sometimes with extreme rapidity, when undergoing the

great pressure of the superincumbent strata in the mine. This gas, it is also known, is itself immediately fatal when breathed instead of air, but when it is mixed with a certain variable proportion of atmospheric air, it becomes highly explosible on the slightest contact with flame. It is much lighter than common air, mixes very readily with it, and, wherever it is poured out into the workings of a mine, rushes with the moving column of air in the nearest direction to the ascending shaft; but, if it meets in its way with any ignited body, there is an immediate and fearful explosion, usually fatal not only to all in the immediate neighbourhood of the accident, but, by means of what is called the *after-damp*, (the gas formed during the explosion, and remaining after it,) involving also in destruction all those in all parts of the workings who are obliged to pass through this noxious gas on their way to the shaft which communicates with the upper air.

This being the case, it becomes an imperative duty of the very first importance, that all possible care and attention should be paid in arranging the underground works of a coal-mine, with reference to these points; namely, first, that the system of galleries should be so contrived for the extraction of the coal that no part shall be left without a current of air passing along it. Secondly, that every communication with old workings in which the fire-damp (as the carburetted hydrogen gas in mines is called) may have collected, should be permanently and effectually built off. Thirdly, that no working should go on in parts of the mine distant from the shaft without every possible precaution being taken to ensure the rapid ventilation of the main passages, and that such distant and detached workings should be as much as possible avoided. Fourthly,

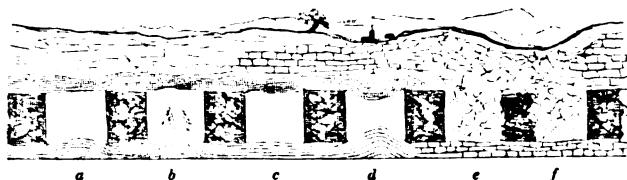
that all possible contact of flame, in a dangerous working, should be prevented, and that this should be attended to not only in the dangerous part of the mine, but in the main passages. And, fifthly, that a steady and effectual ventilation, in every part of the mine not actually cut off by strong partition walls or brattices, should be constantly kept up.

The method of working must, however, be decided on not only with reference to these considerations of safety to the miner from the chance of explosion, but also after all possible information has been obtained, and calculation made as to the sustaining power of the roof and floor, the strata above and below which the coal is deposited. For it must always be remembered that although so long as the coal remains in its place there is no extraordinary pressure, every part being equally and proportionably sustained, yet so soon as the excavation has commenced, and empty spaces are left, the roof, if sufficiently coherent, causes the whole superincumbent weight to act on those portions of coal that may be left in the mine, and which in that case act as pillars.

If then the roof consist of hard sandstone and the floor of soft clay, the pressure downwards will tend to displace and force up the floor, and crush the coal. If, on the other hand, the roof be soft, it will sink in, and if both roof and floor are moderately hard and tough, they will, after a time, meet each other mid-way.

I have endeavoured to represent these different appearances in the annexed diagram, where the roof and floor in the different galleries of which a section is given are in various conditions, produced by the pressure of the superincumbent beds in different ways. The third space to the

right (*c*) represents the gallery with the roof and floor undisturbed, both being hard, and the effects of a soft floor are represented in the first and second compartments (*a*, *b*).



DIFFERENT KINDS OF CREEP IN COAL-MINES.

The effect resulting when both floor and ceiling are soft, are shewn in (*d*), while in (*e*), (*f*) the whole of the roof is represented as having fallen in, the coal is crushed, and the surface of the country exhibits evidence of this underground change.\*

Having acquired a knowledge of the nature of the coal itself, and of its floor and roof, it is always a most important problem to be solved by the coal-viewer, how far he can safely proceed in taking away the coal; and he must also consider whether there is much prospect of his being able ultimately to take a second portion by very carefully and moderately working the seam at first, and in what way the maximum of produce can be obtained, with the minimum of danger and loss.

In the Newcastle coal-field, where the coal is full of gas, where the best seams are worked at very great depths below the surface, and where the strata associated with the coal are often soft and incoherent, it is usual to extract the coal by cutting a number of galleries parallel with each other,

\* The rising of the floor is called in mining language, the *creep*, and marks of its existence are often seen on the surface. The contrary accident, the sinking in of the roof, is called a *crush*, and in avoiding these two accidents consists the difficulty of working the pillars.

and intersected by others at right-angles—thus isolating between four such galleries a pillar of coal whose dimensions vary according to circumstances.

In the description already given of the first operations of mining after the shaft is sunk, it has been mentioned that two levels, the *drift* and *winning headway*, are first completed, and after this other galleries are sometimes driven parallel to the winning headway. These galleries are of different dimensions, the larger ones, which are nine or ten feet wide, are called *boards*, and they are intersected by other galleries at right angles to them whose dimensions are not quite so large, and which are called *narrows*. The pillars of coal left between these galleries are from eight to nine yards thick, and until the close of the last century this method was the only one employed in deep workings, at least sixty per cent. of the coal being left in the mine.

About fifty years ago, however, an attempt was made, for the first time, to remove a part of the pillars, and a method was devised by which 54 per cent. of the coal was obtained, and afterwards, this method succeeding, alternate rows of pillars were abstracted, and sometimes even half the intermediate ones. Lastly, Mr. Buddle invented the method called pannel-work, by which nearly the whole of the coal may be obtained with safety.

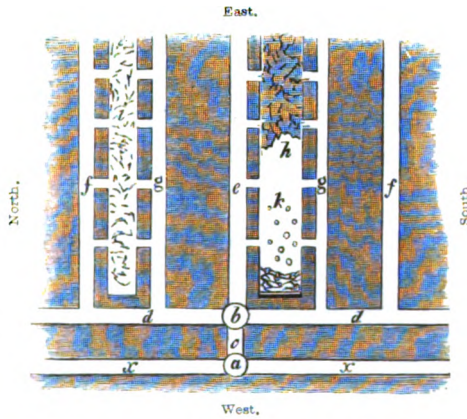
This method consists in dividing the mine into districts or *pannels*, separated from one another by walls of coal forty or fifty yards thick, and extracting the coal from each of such pannels in succession, usually beginning with the one most distant from the shaft, and completely shutting off all communication with the rest of the mine as soon as any pannel is worked out. In the diagram, page 355, and also in page 358, is seen an ideal plan of pannel-work.

Large pillars are at first left between the *boards*, (which are four yards wide,) and the transverse galleries, or *rooms*, (two yards wide,) and the dimensions of the pillars are about twelve yards by twenty-four. As soon as the galleries are finished, and the work of abstracting the pillars commences, the roof is at first supported by stout props of Scotch fir, and when these are also removed, the roof falls in; but the whole of the workings are under the most perfect control so far as ventilation is concerned, and any part can at a moment's notice be shut off from the current of air running through the whole mine, should such an event be required.

The great advantage then of Mr. Buddle's plan is, that while a large proportion of the whole bed of coal may be by its means extracted, the ventilation may be always perfectly well preserved, and the risk of danger from accumulations of gas in old workings almost entirely avoided, because these old workings can be completely cut off from the mine as soon as they become in a dangerous state.

Such being the method of working in mines where there is danger to be anticipated from the fire-damp, let us next shortly consider the nature of the different and simpler contrivances followed in those districts where the coal is not *fiery*, and where the associated beds are sufficiently hard and coherent to support themselves without fear of accident.

In the Yorkshire collieries, as may be understood by examining the annexed diagram, there is something of the regularity observable in the mines of the Newcastle coal-field, but a greater proportion of the coal is worked out at first, and only a wall of coal is left. In the diagram the dip of the coal is supposed to be to the west, and two pits or shafts are sunk, communicating by a gallery called



METHOD OF WORKING COAL IN YORKSHIRE. THE LONG METHOD.

- |                     |   |
|---------------------|---|
| a. Engine pit,      | f. g. Various headways,                           |
| b. Working pit.     | h. The face of coal worked,                       |
| c. Drift            | k. Coal extracted, and roof supported by pillars, |
| d. Horse-gate.      | l. Coal extracted, and roof fallen in.            |
| x. Water-gate.      |   |
| e. Main Board-gate, |   |

the *drift*. From the lower, or engine pit, a gallery is cut on the strike, and likewise another from the working pit, and these are called respectively the water-gate\* and the horse-gate. From the bottom of the working pit a main gallery is also driven on the rise of the coal, and this, which corresponds to the *winning headway* of the north of England, is here called the "main board-gate." Other galleries, parallel to this, are also cut, and the coal is then worked from the intermediate pillars, leaving only a narrow wall, and allowing the roof to fall in after those temporary props are removed which supported it while the works were advancing.

In Staffordshire again, where the seam of coal is of extreme thickness, and consists in fact of several beds united,

\* The word *gate* in Yorkshire retains its ancient meaning, derived from the Saxon verb *gangan*, to go, and is commonly used to signify a road, or way.



the method is somewhat different, as there only a few irregular pillars are left; but there is still a wall of coal, although little regard is paid to those conditions which are justly considered as of the most vital importance in the mines of the Newcastle coal-field.



WORKING THICK BEDS OF COAL IN STAFFORDSHIRE.

*a, b.* The pits.

The system of ventilation must of course be nearly the same in its general plan, whatever be the nature of the mine to which it is adapted, and therefore, in describing the most complicated and perfect arrangements of this kind, as carried on in the fiery seams of Newcastle and its neighbourhood, it will hardly be necessary to mention the smaller degree of the same care and attention paid in the less dangerous workings of other districts.\*

\* Perhaps it is advisable, before proceeding to give a detailed account of the ventilation of coal-mines, that the reader should be made acquainted with some technical terms that will be used in the description.

A *brattice* is a wall of separation. Brattices are of two kinds; either permanent, and separating a shaft into two or more divisions, in which case it is a strong parapet wall, sometimes as much as three feet thick; or temporary, and consisting

There are various modes of inducing the current of air by which the ventilation of mines is to be effected, but the most common is by rarefaction, a powerful furnace being placed at the bottom of the upcast pit. In some cases, however, it is not safe to resort to such an expedient, in consequence of the quantity of gas poured out in the workings; and when, owing to this or any other reason, the furnace cannot be used, a hot cylinder has been substituted, or a current of air produced by throwing a column of water into the downcast shaft, or by pumping out the air by means of an air-pump from the up-cast; but all these are partial and imperfect contrivances, and have many great disadvantages.

The simple furnace has been proved by experience to only of a frame-work of three-inch deal, readily moved to any part of the underground workings.

*Stoppings* are also walls made of brick, stone, or timber, and their object is to prevent the current of air from passing in a given direction.

*Trap-doors* are moveable substitutes for stoppings in the great thoroughfares of the workings. They are of several kinds; as *main-doors*, which are in sets of two or three, and always fixed in the strongest manner, and provided with boys to open them upon a signal, and take care that two of the same set are never open at the same time. *Man-doors* are of small size and communicate with the dangerous parts of a mine. *Sheth-doors* are those which purposely allow a considerable degree of leakage; and *sham-doors* are a kind of trellis-work, only intended to check the current of air.

The *air-course* is a general name for the air traversing workings where ventilation is going on. The fresh air descending into the mine is called the "*in-take*," and that which ascends, after having passed through the workings, is the "*return*."



CROSSING A CURRENT OF AIR IN A COAL-MINE.

A *crossing* is where a current of air crosses another current by means of an arch, as is represented in the annexed diagram.

That part of a mine which is not included in the ventilation is called the *seale*.

be the most convenient method of producing a current of air,\* but before mentioning the additional contrivances of this kind it may be well to say a few words concerning the condition of the underground works, with reference to the ascending and descending current, and the nature of the necessity of such artificial means of ventilating deep coal-mines.

At all great depths below the surface of the earth, the temperature is constant, or at least has no changes corresponding to those which take place on the surface, and it has also been found by experience, that below a certain depth, at which the average temperature of the surface for the whole year is reached, the temperature increases with great regularity.† Thus the air in a deep mine is usually warmer, and therefore lighter, than the external air, and would rise up through a shaft, and be replaced by the colder and heavier air from above. If there were two shafts, an air current would soon be established in the workings, and one of the shafts would become a downcast, and the other an upcast pit, in the technical sense of these words.

But it will easily be seen, that a current of this kind would be very variable, and in extensive workings, where its course is checked by having to pass through a number of galleries, must be totally insufficient for the purpose of ventilation. Where there is a large number of shafts, this evil may, it is true, be avoided in some measure; but in coal-mines where there are very few, a natural

\* A method of producing such a current in coal-mines has been projected by Mr. Goldsworthy Gurney, and is very highly recommended in the report of the *South Shields Committee for the investigation of accidents in mines*. It consists of jets of high-pressure steam applied at the bottom of the upcast shaft, and is meant to be used with rather than supersede the furnace, producing the same effect of rarefying the air in the upcast shaft.

† *Ibid* note, p. 294.

ventilation would not be sufficient even if there were no danger to be anticipated from the escape of foul air.

The effect of a large fire at the bottom either of a shaft, or of a division of the shaft, is to add considerably to the rarefaction of the air as it passes out of the mine, and in this way to produce a rapid ascending column of hot air, whose place is immediately supplied by a rush of cold air from the surface, and this cold air, passing down the other pit, or another compartment of the shaft, and through the workings, is gradually warmed, until at last it reaches the furnace, and itself becomes the ascending column.\*

Such is the advantage of the furnace in assisting to provide a supply of fresh air; but while admitting this advantage, and acknowledging that it is quite as much felt in a single shaft divided into compartments as in the case of two or more shafts having the same total area, it is also right to mention the necessity there is in the former case of having the two compartments quite distinct for a sufficient distance from the bottom of the mine, so as to avoid all risk of the partition wall between them being destroyed by any explosion that may take place.† Mr.

\* The 'standard air-courses,' or, in other words, the supplies of fresh air passing into a mine, vary considerably. In the Wallsend colliery they were stated by Mr. Buddle to vary from two thousand to three thousand cubic feet per minute, but occasionally to reach three thousand eight hundred cubic feet. In some of the large collieries the air has to traverse many miles of gallery before being discharged, and often does not return to the surface in less than twelve hours from the time of its descent. The rate at which it moves varies, of course, according to the circumstances of the mine; but from two to two and a half feet per second is perhaps an ordinary rate, when there is no especial danger. It is sometimes, however, even less.

† Very serious and terrible accidents have happened, owing to neglect in this important matter. After an explosion, it is not at all unlikely that many persons working in a distant part of the mine may be quite uninjured; but if, owing to the want of separate pits or proper precaution, the brattice between the down-cast and upcast shaft is blown away, these unfortunate people must necessarily fall victims; for it will be quite impossible for them to make their way through the



SECTION OF THE BOTTOM OF A SHAFT.

Shewing the subdivision of the lower part  
into two shafts.

Buddle, aware of the great danger incurred with regard to this point, found it expedient to let there be two shafts within a certain distance of the workings, although only one might be carried to the surface.

The air which is to feed these furnaces being that which has passed through, and which carries with it all the impurities of the mine, must often be in an unfit state to support flame, and is occasionally even explosible. In this case the portion coming from the inflammable part of the mine is sometimes separated, and passed by means of an inclined air-course into the shaft, at a safe distance

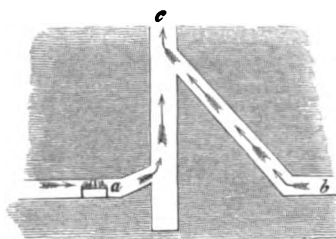


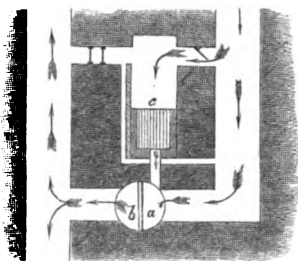
ILLUSTRATION OF A DUMB FURNACE.

*a* the furnace; *b*, the current of foul air drawn up into the shaft (*c*) without being passed over the furnace.

above the fire, this contrivance being called a *cold* or *dumb* furnace. If, however, none of the air that has traversed the mine is fit to supply the fire, a portion of the descending current is sometimes employed for this

after-damp, (which will, in fact, be carried through the workings by the *in-take*,) and there will be no possibility of immediately restoring the ventilation to any part of the underground works.

purpose immediately. A contrivance, by which the air may be thus diverted, is represented in the annexed diagram.

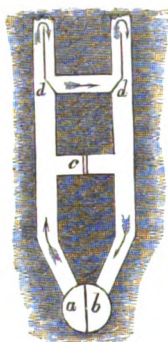


VENTILATION OF COAL-MINES. PARTIAL CURRENT OF AIR TO FEED THE FURNACE.

In this diagram, which represents a plan of the arrangements adopted at the bottom of a pit in the Percy Main Colliery, the shaft is single, but divided by a stout brattice; that part marked (a) is the upcast portion, and (b) the downcast. The air, following the direction of the arrow-head, usually passes by a door into a chamber provided with a furnace at (c), and so into the upcast shaft. Should, however, danger exist, and the current of air become too foul to be safely passed over the furnace, it is forced to pass into the upper part of the shaft, by closing the door; while, on the other hand, a portion of the descending current can be allowed to pass over the furnace immediately by removing the brattices marked in the diagram, and in this way a sufficient draught is obtained to carry the foul air to the surface, without bringing it into contact with the fire.

In the preparatory works of a mine, the ventilation is effected by means very similar to those afterwards adopted in the more extended operations. As soon as a pit is sunk, it is either put into communication with

another pit, if there is one, or if not, the principal gallery, the winning headway, is immediately proceeded with. It



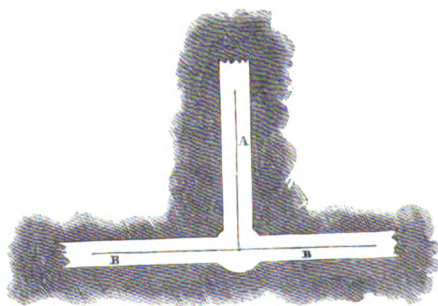
COMMENCEMENT OF WORKINGS IN A COAL-MINE IN TWO PARALLEL HEADWAYS.

a. Downcast pit.  
b. Upcast.

c. Stopping.  
d. Brattice.

is usual, in such case, to drive two parallel headways, which communicate with one another by cross-cuts, called *stentings*, through which the air being conducted, a circulation is immediately established, and as the work advances, and new stentings are required, the former ones are closed by a *stopping*, which is usually a wall of brick. When only one gallery is driven, a moveable brattice is continued from

the bottom of the shaft, forcing the air round by the extremity of the drifts and galleries.



PLAN OF FIRST WORKINGS IN A COAL-MINE. SINGLE HEADWAY.

A. Headway. B. Drift.

Without dwelling on the contrivances formerly in use, let us now turn our attention to an example, in which the

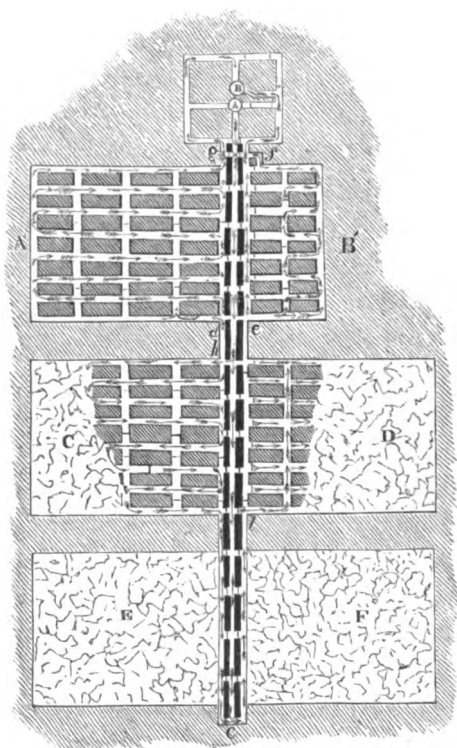
method of pannel-work is followed in the extraction of the coal, and the most complete system of compound ventilation is brought to bear upon an extensive mine. The reader will perhaps require to be informed, that when a current of air is once in motion in the workings it will readily divide itself, and pass along every gallery open to it, provided, of course, that it is able constantly to advance, and is not checked by any wall or stopping. This division and sub-division of the air in the mine, is a matter of great consequence, and was first taken advantage of by Mr. Buddle. I now proceed to describe the working, with reference to the diagram annexed.

In the figure, *a* represents the shaft for the descending, and *b* for the ascending column of air; but they may, also, represent two of the three compartments of a large shaft, the third compartment being used for the general purposes of the mine, but also serving as a descending shaft.

The air arriving at *a*, first enters the *mothergate*, or principal headway, *a*, and when it reaches *d*, divides into three parts, one of which continues along *a*, and the other two enter the compartments *a'* and *b'*, passing into the latter by means of a *crossing*, (not marked in the cut,) such as that figured in page 349. These two currents traverse the *boards* by the method of *coursing the air*, (forcing it to pass through all the galleries,) and the current which traverses *b'* unites with that which has passed through *a'* (traversing the crossing from *f* to *g*) and proceeds directly to supply air to the furnace at the bottom of *b*.

The current which continued along the *mothergate* will be seen to divide again at *h* into two parts, one of which ventilates the compartment *c*, where the pillars are being





IDEAL SECTION OF PANNEI-WORK TO ILLUSTRATE THE METHOD OF  
COMPOUND VENTILATION.

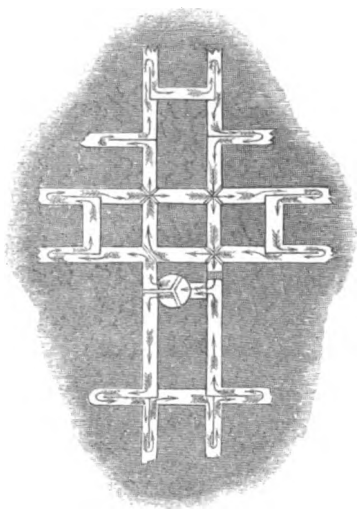
worked out, while the other proceeds along the headway to *l*, and again divides, one part passing into *d*, and the other to the end of the headway. The air proceeding from *c*, after it has traversed those workings, is sent on in one of the galleries parallel to the mothergate, and passing the compartment *e*, which is entirely cleared of coal, unites itself at *c* with a small proportion of fresh air, and then passes before the old works at *f*, and uniting with the current which emerges from *d*, goes through the *dumb furnace* to the ascending shaft *a*.

The air is forced to take this long and tortuous course by means of a proper arrangement of stoppings and trap-doors. The management of these is entrusted to a number of persons, and they are all under the superintendence of a superior class of miners called *wastemen*. It is the *overman's* duty to overlook these latter, and to watch constantly for the slightest changes of appearance that may take place in or near the old workings. The *underviewer*, and his superior the *viewer*, or director of the mine, are responsible for all necessary arrangements, and for the planning of all changes and new works that may be undertaken.

The almost complete command that is obtained by the method of pannel-working, will be now readily understood. The old works E and F, however dangerous, may be cut off entirely from all communication with the rest of the mine, by stoppings in the mothergate; and any one pannel is quite independent of the rest, and may be made to communicate immediately with the purest and freshest current of air in the mine. That portion of the air which passes the most dangerous places, is not passed through the furnace; and an accident may happen in one part, without risking the lives of those employed at a distance.

Perhaps, however, it will give a more distinct notion of the actual perfection of which this system admits, to exhibit a little more in detail, one of the early specimens of pannel-work in a dangerous mine. The annexed diagram is copied from the first illustration by which Mr. Buddle explained his system of compound ventilation. The works are here represented as being very little developed; the two long parallel galleries are the headways; those joining them at intervals the *stentings*, and the shorter

ones, extending irregularly, and opposite one another in sets, are the *boards*. The air, divided at its entrance into the mine into two different currents (indicated by



PANNEL-WORKING.

the arrows), returns ultimately to the third compartment of the shaft; but that only which is supposed to be pure passes over the working-furnace, and the rest following the dumb-furnace, comes into the shaft at a higher level. This will be readily understood by examining the diagram.

The reader will now be able to comprehend the nature of the principle of the most approved system of working coal, but its advantages can only be duly appreciated, when the methods it has superseded are also known. It is due to the memory of the late Mr. Buddle to state, that the most important of these improvements were introduced by him, and that he has thus contributed to

benefit mankind to an extent which it is not easy, perhaps, at present, fully to comprehend.

Having said so much generally on the methods of ventilating coal-mines, I shall conclude this account with a few words descriptive of the process actually followed by the miner in extracting the coal from its bed.

The working tools of the collier are few and simple, and consist chiefly of different forms of the *pick*, the most useful of which is a kind of mattock, with both ends of the head pointed. Besides this, chisels of various kinds, crowbars, hammers, and wedges, make up almost the whole list.

The coal is in almost all cases readily detached by blasting, and is then easily broken up into cubical masses by taking advantage of the natural joints or vertical cracks which traverse it in various directions, and which occur generally in sets parallel, and at right-angles to one another. Besides these the coal is also characterised by what are called *partings*, parallel to the stratification of the beds. The usual method of *getting* the coal is by blasting, and this is effected by piercing the lower part of the seam, with a hole about an inch in diameter, and a yard deep, into which the charge is inserted in cartridges, and the hole is afterwards plugged with coal-dust. When the blast has been fired, the coal is broken up by the workmen, who are usually paid according to the number of tubs, or corves, they are able to fill. These corves are conveyed on tram-roads through the mine, and ultimately lifted by machinery to the surface. The men employed in actually *getting* the coal, are called *hewers*;—the loaded waggons, or corves, are conveyed along the tram by lads called *putters*, as far as the principal galleries, or headways, and are there received into waggons called *rolleys*, several or

which being attached together, they are drawn by a horse to the bottom of the shaft.

I shall not speak now of those contrivances by which the miner is enabled to pursue his work in some degree of safety in those fiery mines where the exposure of flame would be a constant source of imminent danger. The accidents of coal-mines, and the means of preventing them will form the subject of another chapter, in which the *safety-lamp* will be described, and I therefore postpone for the present any further allusion to it.\*

I have already given in the commencement of this chapter, some general statistical facts with regard to the extraction of coal in England, and have spoken at sufficient length of the methods used in extracting it, both in the Newcastle and Yorkshire coal-fields. In these the coal is always of moderate thickness, rarely exceeding a few feet, but in the Dudley coal-field, where, as has been already mentioned, the thickness amounts to thirty or forty feet, both the methods of working and the nature of the dangers and difficulties incurred are very different. The coal is there worked in chambers, called *sides of work*; the ventilation is simple, the danger from fire-damp comparatively trifling, and the principal difficulty arises from the great extent of the valuable part of the seam, and the risk of the upper part falling when the lower is cut away. In many parts of South Wales, and in the Forest of Dean, the mines are worked from the adit level, nor have they been undertaken for a sufficient length of time to require the expensive and

\* I would not be understood to mean that any method of lighting that can be adopted ought for a moment to supersede the most careful and incessant attention to ventilation. Ventilation is beyond all measure the most important, and should almost be looked on as the *only* safeguard against accident; but I postpone the consideration of safety-lamps, as being totally independent of the mechanical details of mining.

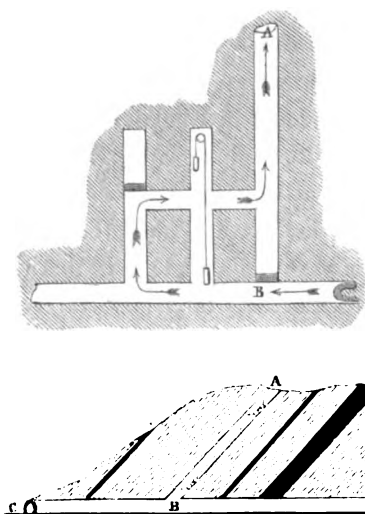
difficult contrivances absolutely necessary in the deeper and longer worked mines of the north.

The great Scotch coal-district, occupying the basin of the Clyde, is worked to a considerable extent by means of numerous small but somewhat deep pits. Most of the large towns of Scotland are supplied from these works.

The coal, as it occurs in England, is generally so nearly horizontal that all the mining arrangements have reference to this position ; but it sometimes happens, both in the east of Scotland, and in South Wales, that the seams of coal are inclined at a very high angle. In both these districts the depth of the shafts is moderate, rarely exceeding 100 fathoms ; and the mine is often open to the day, by means of an adit level entering the lowest part of the workings from a hill side. In Scotland the seams are narrow, the galleries low and wet, and the arrangements on the whole on a very primitive scale ; and until lately, females were often employed in conveying the coal along these narrow levels to the main roads, crawling backwards and forwards with their small carts, in galleries which, in many cases, do not exceed from twenty-two to twenty-eight inches in height.

This painful and unreasonable labour is, however, quite unnecessary, for in Pembrokeshire, and South Wales, where the strata dip at an angle of from  $45^{\circ}$  to  $60^{\circ}$ , the practice of *coal bearing* is entirely unknown. In this district the methods of working are of two kinds, the most common of which is illustrated by the annexed plan and section. The mine is worked by an adit or level coming out on a hill side, and above the adit. Windlasses are fixed at convenient distances on the incline of the vein, and the coal after being brought from the stalls, or places of working, in carts, is dropped by the chain of the windlass

down the incline to the level road ; the empty carts are worked up to the stage of the workings by the opposite chain of the windlass to which they are fixed.



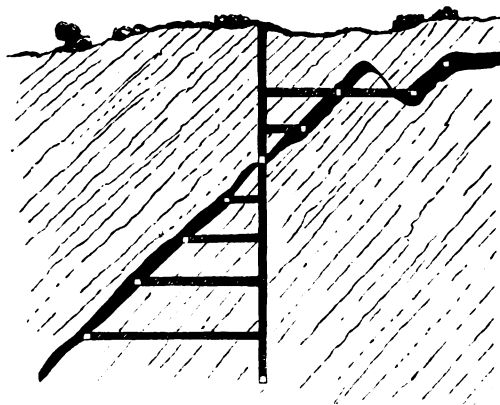
PLAN AND SECTION OF WORKINGS IN PITCHING VEINS IN SOUTH WALES.

If, on the other hand, the coal is worked to the dip, and below the adit level, the coal is, in a similar manner, worked up to a convenient stage by the windlass, and is then taken in the usual way by a shaft to the surface.\*

Besides these methods of working a steep face of coal in England, where, unless the circumstances are in other respects favourable, the extra expense would render the attainment of the coal unprofitable, it has been found necessary on the Continent to have recourse to others, more nearly resembling mining operations in mineral veins. As an example of such methods I have introduced a diagram representing the working of a seam of inconsiderable thickness,

\* Children's Employment Commission. Appendix to First Report, Part II., p. 475.

in the department of the Saône-et-Loire, in France. This working is sufficiently remarkable for some of its details.



WORKING A HIGHLY INCLINED SEAM OF COAL:—EAST OF FRANCE.

In this case the preliminary operations have included eight stages of galleries or levels to meet the seam, all the levels communicating with the same shaft by means of other galleries at right angles (represented in the diagram,) cut in the rock which forms the roof and floor of the vein. The portions of the seam contained between two of the stages have afterwards been excavated by galleries cut on the dip, each portion into which the seam is thus cut being carried away by means of the gallery below it; the successive portions being excavated from above downwards.

In North America, on the other hand, in the State of Pennsylvania and elsewhere, the coal is often fairly exposed to the light of day, and lies in stupendous masses, which are quarried in the open air. The coal is here anthracitic, or non-bituminous, and its thickness is variable, being sometimes fifteen or twenty feet, and sometimes as much as sixty feet. It is much disturbed by faults, but these do not interfere with its being readily and extensively worked.



It may perhaps be expected that I should not quit the subject of coal without, at all events, making some allusion to the much debated question of the extent of workable coal still remaining, and the prospect of its speedy exhaustion. I confess, however, that I am unwilling to add any speculations of my own to the somewhat unsatisfactory conjectures that have been offered on the subject, many of them by Geologists who deservedly rank among the most distinguished cultivators of the science. It has been assumed, indeed, that if the supply continues as large as at present, and from the same mines, provided also that an equally small proportion of the whole coal is obtained, and provided also, we may add, that the price does not materially change, and the waste continues :—that all these conditions being fulfilled, England may find, some few centuries hence, that her northern counties are drained of this most valuable of her mineral treasures. But we may fairly ask, are these conditions at all reasonable ? We have already seen that England is not the only country in the world provided with coal, and there will therefore be competition, and a check thus given to the great consumption from our own mines as soon as they begin to exhibit symptoms of failing. It is said, that the Tyne portion of the northern coal-field is already beginning to be exhausted of the finer kinds of coal, and that the hitherto less worked mines of the Wear and the Tees, have an advantage in commercial competition. And this is only what might be expected. So long as any district affords at once the best and the most convenient supply, it will be worked with the greatest energy, but when it begins to be exhausted, others, before thought inferior, immediately take its place. The great coal-fields of Wales are still almost untouched. Must they not ultimately yield a large proportion of the supply ; and will not such a change take

place gradually, and arrange itself strictly according to the nature of the demand? And even the American mines will doubtless be called on to assist, as soon as the price of their coal can be so far reduced as to compete with that of ours.

I confess it seems to me but a vain thing to attempt any calculation as to the duration of our mineral treasures, as it is a problem for the solution of which there can be no sufficient data. Nor, indeed, can I perceive what useful object is to be gained by the endeavour to make out how many hundred years England may exist, assuming, as it is not unusual to do, that the source of the greatness she has attained is to be looked for in her mineral riches, and chiefly in her large supplies of coal. I am convinced that it is not to the possession of coal or iron, but to the energetic habits of her people, who make the best use of these advantages, that England owes her greatness; and I believe that her resources are strictly within herself, and that so long as her sons press forward in the race, and are earnestly determined not to lose, without a struggle, the high position they have attained amongst nations, so long will she continue fertile in resources, and constantly communicate fresh supplies of life and energy.\*

\* I venture to offer these remarks, not only with reference to such views as they are generally current, but because expression has been given them in the *South Shields Report*, already alluded to, in a manner which I think extremely prejudicial to the fair discussion of many economical questions (and some political ones) connected with the subject. The passage alluded to is the following:—

“Their exhaustion,” speaking of the coal-mines of Britain, “or the cheaper extraction of coal in another country, would bring with it serious injury, if not ruin: every principle of national superiority in her manufacturing and commercial greatness, of which they are the spring of action, would be lost.” See *Report*, &c. p. 3. I confess I do not at all agree with this melancholy prospect; and I think it might easily be proved that it is to the national character of the English people, at least as much as to the existence of valuable coal and iron mines, that her greatness is truly owing.

## CHAPTER VII.

ON THE ACCIDENTS THAT HAPPEN IN COAL-MINES.—VENTILATION,  
SAFETY LAMPS, AND OTHER MEANS OF DIMINISHING THE  
DANGER.

THAT, in the extensive underground works described in the preceding chapters, there should be many casualties and dangers from which men working at their ordinary occupations on the surface are free, can hardly excite astonishment, nor would such occasional accidents call for any special notice were not some of them produced by causes in other respects deserving of careful investigation. Some of these accidents, however, possess a painful interest peculiarly their own, both because of their fearful nature and their frequent recurrence, and it is right that every one should know, while he is enjoying the luxury of his fire-side, on the possession of which, as an Englishman, he might be inclined to pride himself, that, if he proceeds to examine the circumstances under which the coal is extracted from the bowels of the earth, he will discover a vast amount of human suffering and misery necessarily involved before the material can be obtained, upon the due supply of which his comforts so mainly depend.

The cause of the chief of these accidents, namely, the presence of a gas in coal-mines, which becomes explosible on being mixed with a certain proportion of atmospheric air, has been already adverted to in the preceding chapter,

and I have also there enlarged at some length on those methods of ventilating the works of a mine which seem best adapted to avoid the risk thus inevitably incurred. In spite, however, of the most perfect system of ventilation, it appears quite impossible to prevent the occasional accumulation of large quantities of this dangerous gas, more especially in some mines, and some parts of a mine, so that contrivances are necessary, by the help of which even these dangerous parts may be at all events traversed without the risk of an explosion. This necessity was long ago felt, and early in the last century a Mr. Spedding is said to have invented the "steel mill," by which a stream of sparks was produced from the rapid revolution of a rim of steel against flint, and this was supposed to do away with the danger of explosion. Other contrivances succeeded this, but it was not till about the year 1813 that any decided and successful attempt seems to have been made to invent a *safety-lamp*, or in other words, a lamp that could be safely trusted in an explosive mixture of gases.\*

In 1815, Sir Humphrey Davy visited the Wallsend Colliery, to investigate the nature and cause of a number of lamentable accidents that had recently taken place, and the results of this visit, and the circumstances attending it, are thus stated by Mr. Buddle in his evidence before a Committee of the House of Commons in 1835 :—

"I explained to him as well as I was able," Mr. Buddle observes, "the nature of our fiery mines, and that the

\* The proportion of carburetted hydrogen gas, or fire-damp, necessary to be mixed with atmospheric air, in order to render it explosible, is about one fourteenth part. With this admixture there is danger, and the danger increases as more fire-damp is added, until the mixture reaches its maximum of explosibility, at which time the proportion varies from one-ninth to one-eighth. The risk of explosion is not so great when there is a larger quantity of the noxious gas, and when as much as one-fourth part of the mixture is composed of it, it will no longer explode, but begins to be inflammable.

great desideratum was a light that could be safely used in an explosive mixture. I had not the slightest idea myself of ever seeing such a thing accomplished. After a great deal of conversation with Sir H. Davy, and he making himself perfectly acquainted with the nature of our mines and what was wanted, just as we were parting he looked at me and said, 'I think I can do something for you.' Thinking it was too much ever to be achieved, I gave him a look of incredulity: at the moment it was beyond my comprehension. However, smiling, he said, 'Do not despair; I think I can do something for you in a very short time.' To the best of my recollection, within fourteen days he wrote to me to say that he had made a discovery which would answer my object, namely, the procuring a safe light in an explosive mixture. In a few days he sent me down two of the Davy lamps, nearly like those at present used. On the strength of his authority, I took the lamp, tried it first in an explosive mixture on the surface, and then took it into a mine, and it is impossible for me to express my astonishment and delight when I first suspended the lamp in the mine, and saw it red-hot. If it had been a monster destroyed I could not have felt more exultation than I did. I said to those around me, 'We have at last subdued the monster.'"

But alas! the monster was far from being destroyed, and the very confidence so naturally felt, in a contrivance which seemed to answer every purpose of safety, was only the cause of additional accidents in which the fire-damp triumphed yet more signally than ever.\*

\* It is a melancholy, but unquestionable fact, that the number of accidents from fire-damp since the introduction of the Davy-lamp have been many more in a given number of years than before that invention. This has, no doubt, partly arisen from the larger number of persons employed on the whole; but it is to be feared that it has chiefly happened from dangerous portions of a mine being taken into work,

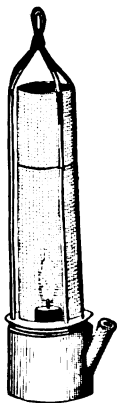
The principles involved in the construction of the *Davy-lamp* are very curious, namely, first, that no mixture of the fire-damp with common air, however dangerous, can be made to explode in tubes, the diameter of which is less than about one-eighth of an inch; and, secondly, that these explosive mixtures require a much stronger heat for their explosion than mixtures of common inflammable gas, since neither charcoal nor iron, when red-hot, will produce this effect (for which purpose, indeed, iron must be raised to a white-heat). Pursuing this discovery, Sir H. Davy found that the length of the small tubes, in which it was impossible to explode dangerous gases, was a matter of indifference, and that a metallic gauze, in which this length was merely the thickness of a fine wire, was quite sufficient for the purpose.

It will be evident, therefore, that by surrounding the light of a lamp entirely by wire gauze whose meshes are sufficiently small, the flame of the lamp will be protected from the effects of an explosive mixture; the mixture will not be fired, and such a lamp may be safely carried where, otherwise, approach would be impossible. The size of the mesh for this purpose is from one-fortieth to one-sixtieth of an inch, and twenty-eight wires, or 784 apertures to the square-inch, are found a defence perfectly sufficient. It should, however, be distinctly understood that even such a lamp may not be used carelessly in any dangerous atmo-

which, without the *Davy*, could not have been attempted, and partly also from the extreme and culpable carelessness of the workmen in removing the wire-gauze, their only protection, and working with an open flame, in spite of every precaution.

It cannot be stated too strongly, that ventilation, and not improvement in the method of lighting, should alone be looked upon as the means of safety. The safety-lamp is invaluable for those whose duties oblige them to traverse the wastes, and direct and superintend the ventilation, and in some doubtful cases even for the hewers; but it ought not to be depended on for more than this.

sphere, for, although perfectly secure when at rest, it seems certain that the rapid motion communicated by the swing of the arm during a hurried transit through the mine, might produce, and probably has, in many cases, produced an explosion. The annexed diagram represents the form of the lamp in most general use.



DAVY-LAMP.

Several improvements and alterations, some of them exceedingly ingenious, have been suggested to increase the safety of this valuable contrivance. It is not, however, too much to say that, while most of these are theoretically much more perfect, they are also more readily injured, and are in every sense less practical. The main fault of the Davy-lamp, and indeed of all the other safety-lamps,

arises from the small quantity of light it diffuses, and the consequent dislike acquired by the miners to its use. No contrivance, however perfect, can by possibility exclude the chance of accident, and the gross, and almost inconceivable carelessness of men whose daily occupation leads them into the most imminent danger cannot be overcome, and can with great difficulty be understood by those not in the habit of constant communication with them.\*

The quantity of carburetted hydrogen gas poured out into the workings of some mines is very considerable and constantly varying. Some seams of coal are much more full of gas than others, and in working these, which are

\* Very remarkable instances of this obstinate and blind perversity are on record ; and in some instances, where danger has been evident and imminent, the workmen have been known to insist on removing the gauze, in spite even of the remonstrances of their companions.

technically called *fiery seams*, it is not uncommon for a jet of inflammable air to issue out at every hole made for the reception of the gunpowder previously to blasting. In the celebrated Wallsend Colliery, in an attempt made to work the Bensham seam (an attempt terminated by a fearful accident) Mr. Buddle says, in evidence before a Committee of the House of Commons,\* “ I simply drilled a hole into the solid coal and stuck a tin pipe into the aperture, surrounded it with clay and lighted it, and I had immediately a gas light ; the quantity evolved from the coal was such that in every one of those places I had nothing to do but to set a candle and then could set a thousand fissures on fire ; the whole face of the working was a gas pipe from every pore of the coal.”

But besides the gas thus steadily and constantly forced into the workings of a mine by a fiery seam of coal, there is always danger of sudden discharges as if from great reservoirs, rushing out from some fissure or small opening in immense quantity and with considerable noise.

These jets are met with in mines perfectly ventilated, and they occur sometimes from the roof, sometimes from the floor of the mine. Several collieries in the north of England are remarkable for constant discharges of this kind, which are collected and conveyed by a tube the nearest way to the upcast shaft.

It would appear, indeed, that coal parts with a portion of its carburetted hydrogen gas or fire-damp when newly exposed to the atmosphere, and this fact explains the circumstance of the coal being more inflammable when fresh from the pit, than after long exposure to the air. But besides such gradual and constant emission of noxious gas,

\* Parliamentary Report. Accidents in Mines, 1835 ; Minutes of Evidence, Qu. 2095.



the jets, or *blowers*, as they are technically called, have often been known to continue in activity for many months or even years together, crevices or fissures in the coal or shale pouring out several hundred hogsheads of fire-damp per minute.\* This phenomenon clearly shews that the carburetted hydrogen must have existed in the cavities of the strata in a very highly-compressed, if not actually in a liquid state, and on the diminution of pressure has resumed its elastic form. Breaking into old workings is likewise a fruitful source of mischief, these spaces serving as reservoirs in which the explosive mixture collects, and is preserved.†

Not only the fire-damp, but some other noxious gases are occasionally met with in coal-mines. Among these the most remarkable is the *choke-damp* or *black-damp*, which is the name given by miners to carbonic acid gas, and this gas is often found in large quantities in old workings, more especially in the Lancashire mines. Unlike the fire-damp, whose specific gravity is very much less than that of common air (0.5382) and which tends to rise to the surface, this gas rests on the floor of the mine, and gradually accumulates, having no tendency to escape beyond a slow mixture which takes place with atmospheric air. Its specific gravity is 1.5277.

But there is another, and more dangerous poison, which has till lately been almost neglected, but the existence

\* An instance of this occurs near Wallsend church, where about four acres of very fiery coal, worked at a depth of about one hundred and fifty fathoms, are drained as it were of gas by a four-inch pipe, which is carried to the surface, and above the chimney, and there ignited. A fiery streamer, of from eight to nine feet in length, is thus constantly kept burning, and the rush of gas through the orifice roars like a blast-furnace. Not less than eleven thousand hogsheads of gas per minute form the average supply collected from these four acres of coal. See the vignette at the end of this chapter.

† Paris' Life of Sir H. Davy, vol. ii. p. 62.

of which, as it is nearly of the weight of common air, (sp. gr. 0.9722) and explodes at a lower temperature than ordinary fire-damp, should be known to all those who are in any way concerned with coal-mining operations. I allude to what is sometimes called *olefiant* gas, or the heavy carburetted hydrogen, which differs in chemical composition from the lighter and more common carburetted hydrogen by the addition of another proportion of carbon. The presence of this gas was suspected by Davy, and its existence has been proved by Professor Bischof in some of the continental mines, in one instance to the extent of 16 per cent.\*

Sulphuretted hydrogen is also sometimes present in mines, and may be the source of mischief, as it readily takes fire when iron, at a red-heat, is exposed in it. The Davy-lamp, therefore, in cases where the ordinary fire-damp would be innocuous, may occasionally be the cause of an explosion if either of these two gases is mixed with the fire-damp, and since the indications of their presence, at least with respect to the former, must necessarily be very imperfect, the danger is of course the greater. Most of these gases when diluted with a moderate proportion of atmospheric air, are, although injurious in their effects when breathed, not immediately fatal. Their presence may often be determined much more clearly by the effect they produce on the lamp, than by any impediment they offer to breathing, and thus it happens that on the one hand a dependance far beyond that which is due is often placed upon this contrivance, while on the other hand its proper warning is neglected, and until the meshes which surround

\* Olefiant gas, when mixed with such proportions of common air as to render it explosive, is fired both by charcoal and iron heated to a dull red-heat. Explosive mixtures of sulphuretted hydrogen also are fired by red-hot iron and charcoal.

the flame are seen to attain a red-heat, the flame itself having been long dull and obscure, no precautions are taken, and no escape from the dangerous vicinity is contemplated. The miner works on in his gloomy cell regardless of the destruction that hovers over him, but when it comes it involves not only himself but all those immediately about him, and too often its effects are yet more melancholy, dooming to a protracted, and comparatively lingering death, many others in distant parts of the mine.

But it is worth while to narrate at somewhat greater length the particulars of one or two of these accidents, from the circumstances attending which some idea of their cause may be obtained.

One of the proximate causes of explosion in workings known to be fiery, is said to be a sudden change in the weight of the atmosphere, indicated by the fall of the barometer. A considerable amount of pressure being thus suddenly abstracted from the surface of the coal, an increased quantity of inflammable gas is discharged, and the mixture with common air takes place rapidly and becomes immediately explosible. To this cause is assigned an accident that occurred in the Bensham seam, worked in the Wallsend colliery in 1821, on which occasion fifty-two lives were lost.

The workings of this pit were subject to be very constantly charged with gas to the firing point; the ventilation had been for some time under the superintendence of two young men, the overmen, whose vigilance had always been successful in preventing any kind of accident.

In consequence, however, of the dangerous nature of the pit, it was placed under the care of the most experienced overman in the colliery, and a short time afterwards the explosion took place, but as the overman, and nearly all

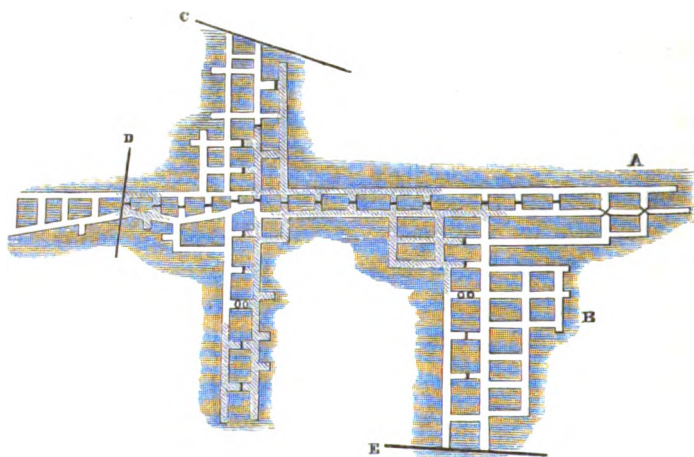
those with him in the pit at the time perished, the immediate cause of the accident could not be distinctly ascertained. At the time of the accident the barometer had fallen suddenly, and stood at 28·8 inches; and it has been remarked as generally observable, that the discharge of inflammable air from the fissures in the roof or floor of a mine diminishes when the barometer is rising, and that the jets of gas, or blowers, already described, are much more intense and powerful when the wind blows from the S.E., and the barometer is low.\*

A very fertile source of accidents in mines is the unexpected arrival at a fault in working, and this is more particularly the case when the fault is connected with a cavity. Great danger then arises if the cavity is filled with inflammable air, as the suddenness and great force of the eruption and explosion gives no warning for the escape of the colliers, or for allowing the person in charge of the ventilation to adopt the necessary measures of precaution. An occurrence of this kind is called by the colliers '*meeting with a bag of foulness*,' and an accident occurred on the 3rd of August, 1830, in the Jarrow colliery, owing to the bursting out of one of these *bags of foulness* from a cavity suddenly met with in the workings. The accuracy and minuteness with which this accident and its cause have been described, render it one of painful interest. It proved fatal to forty-one persons. I have subjoined a plan of the works at the time.

The Jarrow pit is sunk to the Bensham seam, which is worked at 175 fathoms. The seam is nearly horizontal for 176 yards south of the shaft, but is then dislocated by a succession of faults, till it is ultimately settled at a depres-

\* Trans. of Nat. Hist. Soc. of Northumberland, vol. i. p. 185.

sion of twelve fathoms. The pit is situated 360 yards from the river Tyne on its southern bank.



PLAN OF THE WORKINGS AT THE JARROW PIT AT THE TIME OF THE  
EXPLOSION, 3rd. AUG. 1830.

- |  |  |
|--|--|
| A. Winning headway.  | D. Fault, beyond which the fire did not penetrate. |
| B. West workings.  | E. Fault, cutting off the west workings.           |
| C. Fault downcast to the East, the origin of the accident. |  |

The existence of the faults mentioned above was well known from the working of the main coal, and the lower or Bensham seam having been fiery on the north or upper side of the faulty ground, was expected to prove at least equally so on the other side. In prosecuting the works, however, very little inflammable air appeared, either in the coal or in a small set of dykes discovered to the south of the faults. About five or six weeks before the time of the accident, a slight discharge of gas was observed, but it did not increase so much as to become dangerous. The whole tract of workings was limited in extent, and the ventilation perfectly good.

At 5 o'clock on the morning of the accident, the mine was visited by the resident viewer and the under-viewer, and the overman reported to them that 'a bag of foulness' had come off in the east drift, (at c in the plan,) but was soon exhausted, and the place had become 'clean.' The overman's account was, that proceeding to the spot, he found the hewer had come upon a *hitch*, (a small fault not exceeding in amount the thickness of the seam,) and that bearing in mind the former escape of foul air, he expected that another and similar discharge would ensue, and himself laid bare more than a square foot of the face of the fault to examine the circumstances connected with it. He then went into the fore drift, examined the state of the ventilation there, and finding it satisfactory, waited about, until, at the usual time, he repaired to a distant part of the mine, where he expected to meet the viewer and under-viewer, and on their arrival he made his report as above.

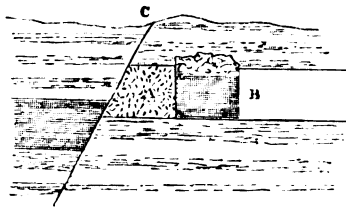
After receiving the overman's report, the whole party proceeded into the first division of the west workings, and were just proceeding to measure off work—their object in the mine—when they were alarmed by a sudden concussion, and whizzing in the air, the well-known indications of an explosion having taken place. Their first impression was, that the accident had happened in a part of the colliery where the pillars were being worked out, distant more than a mile from the place where the explosion really happened. The people who were working at this very spot were also alarmed at the concussion, though at so great a distance.

The first care of the viewers was to collect all the men and boys of that (the west) division of the workings into a group, and endeavour to conduct them safely to the bottom of the pit. At a certain point, however, marked in the

plan by a shaded portion of the gallery, they were met by the *after-damp*, and their further progress was thus checked. Knowing that their lives depended on their being able to force their way through this deadly cloud, they threw themselves upon their hands and knees, stuffed their handkerchiefs into their mouths and scrambled away with all possible expedition, till at the distance of about 120 yards they happily met with the full current of fresh air from the bottom of the pit. They knew by this that the ventilation towards the bottom of the pit had been no further disturbed, and as soon as they had recovered their strength by breathing the fresh air, they began to examine into the state of the adjacent parts of the mine. It was at once seen, that all who might have escaped death from the explosion, must inevitably be suffocated unless the current of fresh air could be immediately forced through the main drift (in which they were), to relieve them. All those, therefore, who had escaped, set to work immediately to put up temporary stoppings, in place of those that had been destroyed, and in this way, if possible, restore the current. As soon as this was done, the strongest of the relieving party were enabled to push forward for some distance, until they were again stopped by the heat and the *after-damp*. It was then but too evident that none of the persons employed in the workings to the east could be living, and as at this point it was also necessary to repair other stoppings before the party could proceed, a number of those in the west workings, who might otherwise have been saved, died from suffocation.

The ventilation was now partially restored, and the workings became approachable. It was found that the effect of the explosion had not reached beyond a four-foot downcast fault to the south, and four men working on the

other side of that fault escaped uninjured. Although the accident happened at about half-past 6 o'clock in the morning, it was not until four in the afternoon that the ventilation was restored in the east workings, and the dead bodies of those who had perished in that quarter were discovered.



CAUSE OF EXPLOSION IN JARROW PIT ILLUSTRATED.

At five o'clock in the afternoon Mr. Buddle visited the mine, and proceeded to examine the workings. On reaching the part where the accident happened (the face of the drift, marked *b* in the annexed diagram,) there was no appearance of inflammable air, but the part laid open by the hewer looked as if an old working had been reached, from which a burst of compressed inflammable air had taken place. The drift was nine feet wide, and five feet high, and the whole block of coal forming the face (weighing about six tons) had been forced forward with great violence, having a jagged-edged aperture on two sides, where it had evidently been detached by some enormous explosive force, leaving a hollow space behind. On removing the mass of coal the cause of the accident was manifest, there being a space of seven feet behind it extending to a small fault and filled with disintegrated coal \* marked (*a*) in the diagram.

\* This disintegrated coal in the cavity did not seem to have undergone any



In this case, therefore, it was evident that a quantity of inflammable air had been contained in a cavity in the vicinity of a hitch, or small fault, and in a state of high compression. It appears, also, that the coal being worked away till the remaining part was no longer able to resist the elastic force of the compressed gas, the gas had escaped with a sort of explosion and filled the adjoining works, and then, as soon as it was sufficiently diluted with atmospheric air, it took fire at the nearest light, and the explosion occurred. No fire had reached the actual face of the drift, nor, indeed, any spot within eight yards of it, and a man working in the drift parallel to and corresponding with the one in which the explosion occurred, and similarly situated with regard to the fault, was suffocated by the after-damp, but not at all burnt.

It is lamentable to find that, from the account of this accident given at the inquest, several premonitory symptoms had been noticed by one of the workmen, but had not been reported by him to the overman. If these had been attended to, and the face of the coal bored for some distance, always in advance of the drift, the gas would have been tapped by these bore-holes and gradually discharged before any risk could be incurred.\*

I have given in some detail the account of this accident, because there are few instances on record in which the history of the explosion is so clear and complete, or which offers more useful matter for contemplation. In most cases of the same kind, it is the melancholy details of individual suffering which attract attention, rather than that calm consideration of the causes that may have led to the acci-

chemical change, but merely to have been crushed by the force which disturbed the strata, and produced the fault.

\* Trans. Nat. Hist. Soc. of Northumb., vol. i. p. 187, *et seq.*

dent, from which alone can be derived any useful hints for future guidance.

The accident which I have just described, in the Jar-row pit, was what is technically called a *smart* fire, in contradistinction to a *heavy* one; the injury done to the mine being trifling, and the fire of small extent, though extremely fatal in its consequences. I now proceed to give a short account of a *heavy fire*, which took place about thirty years ago, just before the discovery of the Davy-lamp, in the Felling colliery; the colliery being at that time looked upon as a model of perfection for ventilation, and comfort in working.

On the 25th of May, 1812, the inhabitants of the villages near this colliery, were alarmed by a tremendous explosion. A slight trembling, as if from an earthquake, was felt throughout a circuit of about half a mile round the workings, and a dull sound of the explosion was heard three or four miles off. Immense quantities of dust and powdered coal rose high in the air, and being blown by a strong west wind, fell in continued showers, and even darkened the air to the distance of a mile and a half from the pit, covering the roads so completely that the footsteps of passengers were strongly impressed in it. This fearful announcement to the neighbourhood, that an accident had occurred from fire-damp, was answered by an immediate rush of the wives and children of the colliers to the mouth of the working pit, and a crowd rapidly collected to the number of several hundreds of persons.

The machine was soon found to have been rendered useless by the explosion, but the rope of the gin (a machine consisting of a drum on a vertical shaft, usually turned by a horse, and used for lowering the workmen and raising the coal) was soon sent down to enable those

who might have escaped the effects of the accident to ascend to the surface. In rendering this assistance the men put their shoulders to the shafts of the gin, doing the work of horses, and by means of great exertion, thirty-two persons were soon brought out alive, and besides them the dead bodies of two boys. Of these thirty-two, three died in the course of a few hours; and the remaining twenty-nine were the only survivors out of a hundred and twenty-one human beings at work in the mine at the time of the explosion.

As soon as it was possible, with any prospect of safety, nine courageous individuals descended, taking with them steel-mills,—at that time the only contrivance known for obtaining light in dangerous workings,—but their progress was soon interrupted by the after-damp, and the sparks from the mill fell into this noxious gas like drops of blood. Deprived of light, and nearly poisoned for want of air, they were obliged to retrace their steps towards the shaft, and then attempted to advance in another direction; but here, also, they were soon stopped by thick smoke, which stood like a wall before them, filling the whole height of the gallery and effectually barring their passage.

They returned with difficulty to the pit bottom, under the full conviction that the mine was on fire; and before all of them had time to ascend, another explosion took place, the men still at the bottom only saving themselves by lying down with their faces to the ground.

Under these circumstances, it was quite clear that all prospect of saving any of the persons remaining in the pit was perfectly hopeless, and the only mode of extinguishing the fire was by closing the pit, and excluding the atmospheric air; but to this many objections were

urged by the friends of the unhappy sufferers, and complaints were made of want of proper exertion on the part of the owners; but they being convinced that the workings were quite unapproachable, refused to offer any reward or inducement to enter the mine. One more attempt was, however, made to proceed from the shaft towards the workings, but it proved equally unsuccessful; and now the smoke issuing from the pit mouth gave such unequivocal proof that the mine was fired, that without further delay the air was excluded, the mouth of the pit being completely closed up. This happened on the 26th of May. Six weeks afterwards the pit was reopened, and in a few days the ventilation was sufficiently restored to allow of the workmen entering the drifts.

On the 8th of July, everything being prepared for the work, nine men descended, and made their way, lighted by steel-mills, in search of the bodies of the unhappy sufferers in the accident. The bodies, mostly in a shocking state of decomposition, were all recovered but one; and all, with the exception of four, were buried side by side, in one trench, in Heworth chapel yard, where an obelisk was afterwards raised over this immense grave, on which the names and ages of the sufferers were recorded.

The ventilation was not sufficiently restored to admit of the working of the mine before the 19th of September, and in little more than a year from that time another explosion took place in the same mine, killing twenty-three, and severely burning thirteen persons.

The mine was intersected with several dykes and fissures, which not unfrequently discharged great quantities of inflammable air from the roofs and floors of the galleries; but it was never satisfactorily proved whether the accident was owing to the falling in of some

matter in the wastes, interfering with the regular course of the ventilation, or whether, by some neglect, the furnace was not acting properly at the bottom of the upcast pit. The general condition of the ventilation was so good, that the workmen declared they never wrought in a pit so wholesome and pleasant.

But terrible as the danger is, and fearful as are the accidents resulting from the presence of inflammable air in coal-mines, these dangers are not the only ones that must be braved by the pitman in his underground work, and in many cases he is exposed to accident from water as well as fire.

As an instance of this, in the year 1815, seventy-five persons were drowned in the Heaton Main colliery; the old workings of another colliery, in which the water had accumulated, rushing into the works, which were carried on in ignorance of the proximity of these old mines. Accidents of this kind have also frequently happened in other coal-fields, and it is only a very few years since one of the principal collieries of Whitehaven, carried on under the bed of the ocean, was suddenly and completely destroyed by the incursion of the sea into the workings.

One of the most interesting of the accidents of this kind on record occurred in 1833, in an extensive Scotch colliery, of which the workings were so much injured by the irruption of a river into them, as to be afterwards almost useless.

On the 20th of June, in the year above mentioned, two gentlemen fishing in the river Garnock, observed nearly opposite to where they were standing a slight eruption, which they supposed at first was occasioned by the leap of a salmon; but a gurgling noise which succeeded, led them to suspect that the water had broken

into one of the coal-mines surrounding the spot. With this idea they hastened to the nearest pit mouth to give warning; but their notice was neglected, as too improbable to be worth attending to.

Before very long the workmen were found to be making their way to the bottom of the shaft, several of them being up to their necks in water when they reached it. All of them, however, escaped with life, and as soon as they reached the surface they proceeded at once to check, if possible, the rush of water into the mine, by filling the cavity in the bed of the river with straw, clay, &c.; but their efforts were vain, for the water continued to pour in steadily till the following afternoon, when a large space of the bed of the river was broken through, and the whole body of the stream was in a short time engulfed, its bed being left dry for more than a mile. The river was affected by the tides, and this engulphment took place at low water, but as the tide rose, the sea entered with prodigious force, and the sight was impressive beyond description, the water continuing to pour in till the whole workings, extending for many miles, were completely filled, and the river resumed its ordinary appearance.

No sooner, however, had this taken place, than the pressure of the water in the pits became so great, that the confined air, which had been forced back into the high workings, burst through the surface of the earth in a thousand places, and many acres of ground were seen to bubble up like the boiling of a cauldron. Great quantities of sand and water were also thrown up, like showers of rain, during a period of five hours, and an extensive tract of land was laid under water, by which from five to six hundred persons were entirely deprived of employment.

Many other accidents occur besides these of fire and water, and some of them are occasionally fatal ; but as they are, for the most part, dependant on local circumstances, and must be looked on rather as ordinary casualties, which, however melancholy, can not be entirely prevented, and belong more or less to all kinds of employment, I shall not here detain the reader by dwelling upon them. Those connected with the imperfection of machinery, such as the bursting of steam-boilers, the breaking of ropes, disarrangement of the winding machinery, and others, are gradually becoming fewer, and with proper care may be reduced to a very small number ; but so long as coal-mines continue to be worked, so long will there be a succession of victims to the fire-damp, a 'monster' which no art of man is ever likely to render harmless.

The fiery seams, if they must be worked, cannot be worked without danger, and the extent of this risk it is truly painful to contemplate, for it appears that, in the southern part of the Newcastle coal-field alone, nearly seven hundred miners have met with death by explosions of fire-damp within the last twenty years.

Some sympathy is certainly due, then, to that large class of our fellow-subjects, who contribute so painfully to our comforts and enjoyments ; and, with reference to this subject, I may appropriately quote the following remarks on the accidents of coal-mining, from the Report of the South Shields Committee, already more than once referred to.

" Pit coal," it is there said, " is produced by a severity of labour and risk of personal safety to the miner, which the workman of no other occupation is exposed to.

“ The pitman descends 200, 300, and sometimes more than 500 yards into the bowels of the earth, and there traverses subterranean passages, frequently from two to three miles in extent, to his work ; where by the glimmering of a small candle, or more imperfect lamp, in a space seldom six feet high, and oftener three or four, he labours in a stooping posture, sometimes lying on his side for eight or ten hours together, in an impure atmosphere, to extract the mineral that aboveground is diffusing light, heat, riches, and enjoyment.

“ In such a situation, often without a moment’s warning, he is overtaken by destruction. The gases generated in such abundance in the mine, from some accident suddenly explode, and fill the pit with death. In an instant, and in the most fearful manner, he is scorched and shrivelled to a blackened mass, or is literally shattered to pieces against the rugged sides of the mine ; or, if out of the immediate range of this terrible piece of ordnance, in a few seconds the *after-damp* spreads itself in every direction, and poisons beyond recovery all that it may reach. Humanity has too frequently to deplore these fearful accidents.”\*

That these accidents are most deeply to be lamented there cannot of course be one moment’s question, and the only matter that remains for consideration is whether by any legislative measure, or by any application of human ingenuity in the arrangement of the workings, some greater degree of safety cannot be introduced, and some portion at least of this fearful destruction of human life be checked.

One thing at any rate is certain, and it cannot be too often repeated, or brought too frequently under the consideration of the owners of coal property, namely, that

\* Report, &c., p. 3.



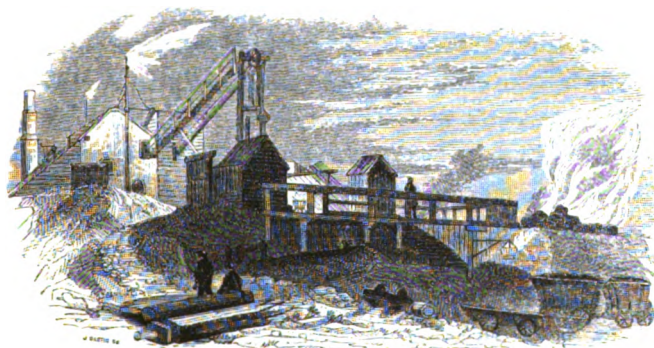
greater security must not be looked for by any kind of lamp that may be contrived, but in the improvements that may be effected in the ventilation of the mines. This is the only real principle of safety, for this is the only possible means of rendering harmless the noxious air given out in such abundance beneath the surface of the earth.

There are, however, doubtless many practical difficulties in the way of increasing the quantity of fresh air in a mine, and these are greater as the mine is deeper and more extensive and the property more valuable, but it does seem, from the evidence of unprejudiced persons, that in many cases the extent of air-passages, ventilated by a single shaft, is far greater than it ought to be, and greater than will admit the possibility of effectual control. .

That this is no exaggeration, appears from the evidence adduced in the South Shields Committee Report,\* where it is stated that in one instance only, a single pit of thirteen-and-a-half feet diameter is allowed for the ventilation of between seventy and seventy-five miles of passages, the pit being used besides for drawing the coals and pumping water. This pit is eight hundred and fifty feet deep ; the mine is worked to the extent of four hundred acres, and the supply of air moves only at an average rate of one-and-one-tenth foot per second through considerably more than one-half the mine. Several other instances even more striking, are quoted in the Report from which these details are obtained, and it seems only reasonable to assume, that while such a condition of the deeper and more extensive mines is allowed to continue, those means are not taken which alone can justify the owners of the property in working mines known to contain a large quantity of noxious and dangerous gas.

\* Report, &c., p. 31.

Various methods have been suggested by which the rate of motion of the column of air, made use of to ventilate a mine, may be increased by mechanical contrivances, and it has also been proposed that the area of the upcast shaft, bringing the warmer, and therefore expanded air, to the surface, should be larger than that of the downcast. These methods may well be the subject of inquiry and investigation, but perhaps they have not yet been sufficiently matured to be brought into use on a large scale. There will also be a difficulty in inducing the coal-owners and others to introduce them, involving, as they often do, theoretical applications of some principle not generally understood, and being more frequently proposed by speculative men, strangers to the actual operations of mining, than by those practical, as well as scientific persons who have an admitted public claim on attention.



WALLSEND COLLIERY.

## CHAPTER VIII.

THE MISCELLANEOUS APPLICATION OF MINING PRINCIPLES :—  
IRON-MINES :—SALT-WORKS.

THE vast preponderance in the value of the iron above that of every other metal obtained in England, and even above all of them taken together,\* renders it necessary that I should devote some space here to describe the working of those ores from which the supply is chiefly derived ; and I shall also allude shortly to the methods adopted in order to obtain the metal in the state of what is called ' pig.' Of the further processes by which it is rendered malleable, I shall say nothing, as they belong strictly to the subject of metallurgy.

The principal districts in the British Isles from which iron is obtained are three, the South Welsh, the South Staffordshire, and the West of Scotland.

The beds of ironstone being interstratified with the coal, and the sandstones and shales of the coal-measures, they are usually raised from the same pit as that by which the coal is extracted. The thickness of the ore, however, being generally only a few inches, it is worked in a manner somewhat different.

Near Bilston, in the South Staffordshire district, there

\* It is stated in Sir H. de la Beche's Report of the Geology of Cornwall, that the value of the iron annually obtained from the ores in the United Kingdom may be estimated at eight millions sterling, while that of all the other metals together scarcely exceeds two millions and a half. This amount will be seen to be far less than that given in the table, note, p. 303. It appears, however, that M. Burat has calculated the value of the metals by a different scale.

are as many as seven seams containing ironstone, all distinguished by technical names, but many of them not more than five or six inches in thickness, and alternating with claystones not containing iron. Two of the ironstone bands are thicker and more valuable than the rest, and they, as well as all the others that are worked, lie beneath the ten-yard seam of coal in the district. The seams are, if possible, worked two together, the intermediate stuff being of no value, but removed to form a gallery, and afterwards piled up to support the roof, when the ore has been obtained. The nature of the work is sufficiently simple; the miner usually lying on his right side, and striking with the pick to remove the ore and the intermediate clay. This method may seem a disagreeable one, but the galleries are cooler than the coal-mines at the same level, although they are also wetter and dirtier. The ironstone is of a dull brown or yellowish colour; it very often occurs in the shape of flattened spheroidal balls, and is traversed by cracks and fissures which have become filled with carbonate of lime. The centres of the spheroids often exhibit an organic nucleus.

There is considerable danger in working these mines from the occasional falling in of a portion of the roof, but they are usually almost entirely free from noxious gases.

The iron district of South Wales supplies a large proportion of the whole amount of this metal raised in the British Islands. It is identical with the great coal-field of that district, the ironstone bands being always associated with the various beds which make up the carboniferous series.

The bands of ironstone here, as in Staffordshire, are usually not more than a few inches thick, and the workings are, therefore, as narrow and low as possible. They

are often inclined at a considerable angle, and this position is taken advantage of by working in levels which communicate with a lower part of the shaft by galleries run on the dip of the vein.

“The distribution of the ore among the limestone, which in the Forest of Dean forms its matrix, is sometimes very remarkable. It lies in ‘*churns*,’ or ‘*pockets*,’ as the miners term these deposits; and as the ore is cut away, natural pillars and arches of limestone are left supporting the roof in a variety of grotesque forms and combinations. The contents of the churns vary both in quality and quantity, producing a picturesque irregularity in the mine-works, strongly contrasting with the even courses of the coal strata.”\* Accidents are said to happen very frequently in these mines, from the workpeople neglecting to prop up the roof with timbers as they proceed.

The iron works in Glamorganshire and Pembrokeshire are sometimes so near the surface as to be obtained without a shaft or regular galleries. In other cases, they are worked from an adit level, which comes out to day on the side of a hill.

The iron district of Scotland contains a vein of ore, (called *the black band*,) much richer than any of those met with in South Wales or Staffordshire.† This valuable stratum is extremely local, not being known to exist in perfection beyond a space of from eight to ten square miles; but similar deposits of inferior quality are sufficiently abundant.

Although, however, the true black band is so narrowly

\* First Report of Commissioners on Mines. Appendix, Pt. ii. p. 4.

† It is said that a black band resembling the bed so celebrated in the Scotch iron-works has lately been discovered in South Wales. The effect of this upon the price of Welsh iron will shortly appear if there is any abundance of the ore, and it must, in that case, be very injurious to the Staffordshire works.

confined in its distribution, there are no less than four principal and valuable seams of ironstone in the Lanarkshire district, three of which are of very superior quality. These measure from fourteen to eighteen inches each in thickness, and when roasted yield from 60 to 70 per cent. of iron, requiring not more than six cwt. of limestone as flux, instead of from twenty to thirty cwt. (as the poorer and less fusible ores do) to produce the ton of metal.

The principal circumstance which has given an impulse to the iron-manufacture in Scotland, and consequently caused a most rapid increase in the iron-works in the neighbourhood of Glasgow and elsewhere, is the invention of the hot-blast, but the method of applying a blast of heated air during the smelting of iron ore was progressively developed, and has been gradually gaining ground for many years. The general plan now adopted, not only in Scotland, but in the English iron-mine districts, is to drive the air from the blowing-cylinders through a number of flattened tubes of iron, arranged within a furnace of brick-work, and the tubes being rendered red-hot the blast is made to enter the smelting furnace at a temperature of 600° Fahrenheit—a heat somewhat more than sufficient to melt lead. The advantages which result from this arrangement are,—1st. A great saving of fuel, as about two and a half tons of raw coal now do as much service as the coke derived from eight tons when used with the cold-blast. 2. The saving in labour and time in doing away with the coking; and 3. Nearly double the quantity of pig iron produced from the furnace in the twenty-four hours.

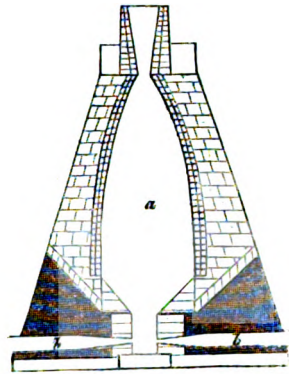
It has, indeed, been considered, that the iron produced in this way by the hot-blast is not economical in the farther processes of reducing it to a malleable state; but

there can be little doubt, that the method will ultimately succeed, and take the place of the cold-blast, in spite of the prejudices that at present exist against it.

Let us proceed now to consider shortly the nature of the processes by which the ironstone is converted into the state of metallic iron.

Carbonic acid and clay enter very largely into the composition of most of the iron ores used in England, and a small proportion of water, sulphur, silex, and sometimes arsenic and other metallic ingredients are also present. The percentage of iron varies greatly—what is generally used containing from 18 to 50 or 55 per cent., while the average may be stated at about from 30 to 35 per cent. The black band, and the other rich ores of Scotland, contain, however, a much larger proportion.

The first operation is generally that of roasting, or calcination, performed in kilns, and the object of this is to get rid of the water, sulphur, and other impurities. The roasted ore, sometimes mixed with a portion of richer ore, is afterwards smelted in the blast furnace, being assisted by a certain proportion of limestone, or other substance, which combining with the clay of the ore, and forming with it a fusible compound, runs off during the smelting in a slag or cinder, leaving the iron in a melted state at the bottom of the furnace. In order to obtain this result, the roasted ore is put into a furnace of a peculiar shape and construction, with a certain quantity of coke and flux, and is there exposed to an intense heat. A section of the furnace used (called a blast-furnace) is represented in the accompanying diagram, and its mode of action is readily explained. The furnace is strongly built round with masonry, and the interior *a*, (from 14 to 17 feet in diameter in its broadest part), is lined with fire-



SECTION OF A BLAST-FURNACE.

*a.* The Boshes.*b.* The Twyeres.

bricks, and gradually diminishes in size to the cylinder at the top, called the tunnel head, where its diameter is not more than seven, eight or nine feet. Below the broadest part the dimensions also diminish rapidly, and at length terminate in a small cylindrical or cubical portion called the hearth, the walls of which are provided with recesses for the introduction of the blast. The hearth is either made of coarse grit or of firebrick, and measures about three feet each way. The whole height of such a furnace would be 55 or 60 feet; but this is a large size, and the furnaces, in many parts of the country, are not nearly so extensive.

The furnace being thus contrived, the blast is applied by means of pipes passing into the furnace through holes provided in the hearth called *twyeres* (*tuyères*, tubes) *b*, see diagram. Sometimes two, but occasionally three twyeres are used, and the management of them requires very considerable skill. The blast is produced by powerful steam-engines moving blowing-pistons, and is regulated by being passed through a closed vessel.



The furnace being first thoroughly heated, is in a condition to receive the materials for smelting, and these consist of a due admixture of ore, coke, and flux, from the mutual action of which during combustion the iron is obtained. The materials are introduced at the tunnel head by the filler, and the proper number of charges added from time to time, in order to keep the furnace full during twelve hours, at the end of which time the lower part is tapped, a hole being opened on a level with the bottom of the hearth, and in front of the furnace. Besides this aperture, there is also a hole level with the top of the hearth by which the liquid scoria, or cinder, is constantly running off, while the iron sinks down to the bottom. The appearance of the cinder is a very accurate index of the changes going on in the furnace, and generally indicates the quality of the iron that is about to be run out. The iron is run out into furrows prepared in sand, and the semi-cylindrical portions thus obtained are called pigs, the iron in this state being pig-iron. When the running is completed, the hole is stopped up with a mixture of sand and clay, the charges are continued, and the operation goes on without any cessation, the furnace being kept in constant work for months, and the running taking place every twelve hours.

The quantity of iron manufactured in the British Isles is greater, perhaps, than could readily be imagined. In the year 1839, the South Welsh district, including the Forest of Dean, produced 533,000 tons, South Staffordshire 367,000, and Scotland 200,000; so that, including the amount made in other parts of the country, the total produce must have reached one million three hundred and forty-eight thousand tons. In order to obtain this quantity of pig-iron, it is calculated that upwards of four mil-

lions of tons of ore, a million and a half tons of limestone, and seven millions of tons of coal, were extracted from the bowels of the earth, and that, at the lowest calculation, the labour of a hundred thousand human beings, besides steam-power, was employed in first raising, and then reducing the ore.

Besides the supply of iron ore associated with coal in England, a considerable quantity is also obtained in a similar way from the mines in France, Belgium, and North America. In each case the mines have been worked with great vigour, and some attempts have been made to rival the English in this great article of export trade.

Although, however, every encouragement, even to the laying on of a protective duty to a considerable amount, has been offered by foreign governments, and much iron has accordingly been made, the great advantages possessed by our own country, are of a nature hardly to be injured by foreign competition. Our iron ore is situated in those districts where coal is cheapest, the ore itself is sufficiently abundant, the necessary flux is at hand, and fire clay—no unimportant article in the building of the furnaces, on whose long-continued working so much depends—is found in the same ground as the ore itself. The largest and most complete manufactories have long been established in the most convenient places and with an almost unlimited amount of capital, the most perfect and the cheapest communication by water is open to all parts of the world; the further processes which the metal has to undergo are performed at once on the spot, in the best manner and at the smallest possible expense, and nothing can surpass the enterprise of the great iron-masters. Nothing, in short, but English energy and perseverance, with resources such as England only knows, can ever interfere in her iron trade, within certain

limits of distance and expense of transit. Beyond those limits our trade must always be doubtful, and to a certain extent forced and unnatural.

## SALT-MINES.

THE salt-mines of Cheshire form so legitimate a branch of the great mining operations of our country, that they well deserve notice among the applications of mining principles now under consideration. These mines, and the brine-pits of Worcestershire, not only supply sufficient salt for the consumption of almost the whole of England, but upwards of half a million of tons, for the most part the produce of the neighbouring county of Cheshire, are annually exported from the port of Liverpool.

The immense deposits of rock-salt from which this great supply is obtained, are strictly confined in England to the marls of the New red sandstone formation, and they are not universally distributed, but only met with in two or three counties skirting the principality of Wales. In Cheshire the salt occurs in large quantities in the condition of an impure muriate of soda, and associated with a peculiar marl: it is sometimes massive, and sometimes existing in large cubical crystals, and the beds containing it usually alternate with considerable quantities of gypsum or sulphate of lime, although this latter mineral is not worked to profit.

The appearance of the rock-salt is by no means of that brilliant character, nor has it the delicate transparency, and bright reflecting surface, which the reader may perhaps suppose characteristic of it. It is usually of a dull red tint, and associated with red and palish green marls ;

but it is still not without many features of great interest, and when lighted up with numerous candles, the vast subterranean halls that have been excavated present an appearance richly repaying any trouble that may have been incurred in visiting them.

In Nantwich and the other places in Cheshire where the salt is worked, the beds containing it are reached at a depth of from 50 to 150 yards below the surface. The number of saliferous beds in the district is five, the thinnest of them being only six inches, but the thickest nearly forty feet thick, and a considerable quantity of salt is also mixed with the marls associated with the purer beds.

The method of working the thick beds is not much unlike that already described in speaking of the thick coal-seams of Staffordshire and Shropshire. The roof, however, being more tough, and not so liable to fall, and the noxious gases—with the exception of carbonic acid gas—totally absent, the works are more simple, and are far more pleasant to visit. Large pillars of various dimensions are left to support the roof at irregular intervals, but these bear only a small ratio to the portion of the bed excavated, and rather add to the picturesque effect, in relieving the deep shadows and giving the eye an object on which to rest. The intervening portions are loosened from the rock by blasting, and it may be readily understood that the effect of the explosions heard from time to time, and re-echoing through the wide spaces, and from the distant walls of rock, give a grandeur and impressiveness to the scene not often surpassed. The great charm, indeed, on the occasion of a visit to these mines, even when they are illuminated by thousands of lights, is chiefly owing to the gloomy and cavernous appearance, the dim endless perspective, broken by the numerous

pillars, and the lights, half disclosing and half concealing the deep recesses which are formed and terminated by these monstrous and solid projections.

The descent to the mines is by a shaft, used for the general purposes of drainage, ventilation, and lifting the miners and the produce of the mine. The shafts are of large size in the more important works, and the excavations very considerable, the part of the bed excavated amounting in some cases to as much as several acres. Over this great space the roof, which is twenty feet above the floor, is supported by pillars, which are not less than fifteen feet thick. The Wilton mine, one of the largest of them, is worked 330 feet below the surface, and from it, and one or two adjacent mines, upwards of 60,000 tons of rock-salt are annually obtained, two-thirds of which are immediately exported, and the rest is dissolved in water, and afterwards reduced to a crystalline state by evaporating the solution.

The mines, however, are not the only sources from which salt is obtained, and it is only since the year 1670, when the beds were discovered during an unsuccessful sinking for coal, that the actual rock-salt, as a mineral, has been dug out from the mine. Before that time the chief supply was obtained from the brine springs of Droitwich, near Worcester

Among the most remarkable of the rock-salt mines in Europe, are those of Altemonte in Calabria, Halle in the Tyrol, Cardona in the Pyrenees, and Wieliczka in Poland. These are all interesting, and each exhibits phenomena peculiar to itself, but I must not detain the reader with an account of individual mines.

The deposit of salt in the valley of Cardona, in the Pyrenees, is, however, too remarkable to be passed over.



MASS OF ROCK-SALT. CARDONA IN THE PYRENEES

In this spot two thick masses of rock-salt, apparently united at their bases, make their appearance on one of the slopes of the hill of Cardona. One of the beds, or rather masses, has been worked, and measures about 130 yards by 250, but its depth has not been determined. It consists of salt in a laminated condition, and with confused crystallisation. That part which is exposed (see the wood-cut) is composed of eight beds, nearly horizontal, and having a total thickness of fifteen feet, but the beds are separated from one another by red and variegated marls and gypsum. The second mass, not worked, appears to be unstratified, but in other respects resembles the former, and this portion, where it has been exposed to the action of the weather, is steeply scarped, and bristles with needle-like points, so that its appearance has been compared to that of a glacier.

Perhaps a better idea of the nature of mines of this kind will be obtained by the following general account of a visit to the Polish salt-mine of Wieliczka, than by dwelling on the details of the workings, which are nearly

the same in most cases. This visit took place seventy years ago, and gives, therefore, a picture of the mining contrivances of that date, but little change has taken place up to the present day.

The manner of descending into the mine was by means of a large cord wound round a wheel, and worked by a horse; and the visitor, seated on a small piece of wood placed in the loop of the cord, and grasping the cord with both hands, was let down two hundred feet, the depth of the first galleries, through a shaft about eight feet square, sunk through beds of sand alternating with limestone, gypsum, variegated marls, and calcareous schists. Below the first stage, the descent was by wooden staircases, nine or ten feet wide.

In the first gallery is a chapel measuring 30 feet in length, by 24 in breadth and 18 in height, every part of it, the floor, the roof, the columns which sustain the roof, the altar, the crucifix, and several statues, all cut out of the solid salt. It does not, however, appear that the salt in these mines is purer, or better adapted to produce those magic appearances which have sometimes been imagined, than the same mineral as it occurs in the mines of Cheshire.

The manner of obtaining the salt in the Polish mines at the time of the visit we are recording was peculiar and ingenious, but has since been partly superseded by the use of gunpowder. In the first place, the overman, or head miner, marked the length, breadth, and thickness of a block he wished to be detached, the size of which was generally the same, namely, about eight feet long, four feet wide, and two feet thick.

A certain number of blocks being marked, the workmen began by boring a succession of holes on one side

from top to bottom of the block, the holes being three inches deep and six inches apart from one another. A horizontal groove was then cut half an inch deep both above and below, and having put into each of the holes an iron wedge, all the wedges were struck with moderate blows, to drive them into the mass. The blows were continued until two cracks appeared, one in the direction of the line of holes, and the other along the upper horizontal line. The block was now loosened and ready to fall, and the workman introduced into the crack produced by the driving of the wedges a wooden ruler, two or three inches broad, and moving it backwards and forwards on the crack, a tearing sound was soon heard, which announced the completion of the work. If proper care had been taken, the block fell unbroken, and was then divided into three or four parts, which were shaped into cylinders for the greater convenience of transport. Each workman was able to work out four such blocks every day, and the whole number of persons employed in the mine, varied from twelve hundred to about two thousand. The mine was worked in galleries, and it was said that, at the time of the visit, the account of which I have just given, the extent of these galleries was at least eight English miles. The excavations are now much more extensive.

The method of preparing the rock-salt, and the processes employed in manufacturing salt from brine springs, is nearly the same in all salt-works. The first process is to obtain a proper strength of brine, either by saturating fresh water with the salt that has been brought up from the mine, or pumping up the salt water from springs that have become saturated by passing through saliferous beds. The brine obtained in a clear state is put into evaporating pans, and brought as quickly as possible to



a boiling heat, (in the case of strong brine  $226^{\circ}$  of Fahrenheit,) when a skin is formed on the surface consisting chiefly of impurities. This is taken off, and either thrown away, or used for agricultural purposes, and the first crystals which form are likewise raked away and thrown aside as of little value. The heat is then kept up to the boiling point for about eight hours, during which time evaporation goes on steadily, the quantity of liquid becoming gradually reduced, and the salt being deposited. It is then raked out, put into moulds, and placed in a drying stove to render it perfectly dry, and ready for sale. The finer kinds of salt are made by evaporating at a lower temperature, and of course require a longer time to produce; while a still coarser kind than that obtained by the rapid evaporation of brine, is sometimes made from sea-water and salt-springs, by merely solar evaporation, the water being exposed in large pans, or passed through a succession of frameworks of numerous small twigs, so contrived as to expose a very large surface to the air. The salt obtained from sea-water is called bay-salt, and possesses many impurities from which the other kinds are free. It may be worth while to mention, that the proportion of salt obtained from strong salt-springs, varies from  $3\frac{1}{2}$  to  $6\frac{1}{2}$  per cent., but in sea-water does not exceed  $1\frac{3}{4}$  per cent.

## CHAPTER IX.

THE MISCELLANEOUS APPLICATION OF MINING PRINCIPLES (*continued*).—GYPSUM AND ALABASTER WORKS.—ALUM-WORKS.—LIGNITE AND BROWN COAL.—QUARRIES AND OPEN WORKINGS.

## GYPSUM AND ALABASTER.

GYPSUM, or sulphate of lime, and the peculiar form of that mineral called Alabaster, are substances of considerable importance in the arts, and possess also a certain amount of interest for the Geologist. Rendered more valuable by a slight admixture of carbonate of lime, the gypsum of Montmartre, near Paris, has long been celebrated for its excellence as a cement when burnt (forming the well-known plaster of Paris). The variegated alabasters of Italy, Derbyshire, and elsewhere, are so ornamental and beautiful as to possess considerable value; while the pure white varieties are employed in the manufacture of porcelain and the glazing with which it is covered; and the coarser kinds are advantageously used as a top-dressing for many soils. All the different varieties of gypsum, when exposed to heat, are deprived of their water of crystallization, and become opaque, falling into a powder, which, if mixed with water, speedily hardens on subsequent exposure to the air.

Marls containing gypsum are found in various geological localities, and are often associated with saliferous beds. The chief deposits of this mineral in England are in the

New red sandstone of Cheshire and Derbyshire. In the neighbourhood of Paris, the extensive gypsum beds of Montmartre form an important part of the older Tertiary series of deposits in that locality. In Germany and the Vosges, the beds of the Triassic system (corresponding to the New red sandstone of England) are its chief depositaries; while in Russia, and apparently also in North America, it abounds in the older strata of the Magnesian Limestone, or Permian system.

The gypsum of Montmartre is worked chiefly in quarries, and is remarkable for containing in great abundance the fossil remains of quadrupeds. It is found resting on a limestone of marine origin, and forming a range of hills, whose peculiar aspect (resembling elongated cones) may be recognised from a distance. These hills are distinctly superimposed on lower hills of much greater extent.

There are two masses of gypsum at Montmartre, the lower of which is composed of beds abounding in selenite, (the crystallized sulphate of lime,) and alternating with finely-laminated argillaceous marls. The upper mass is both the most important and the thickest, attaining in some places a thickness of nearly twenty yards. It contains very few marly beds, and in some places appears immediately beneath the vegetable soil, and is readily and conveniently worked without any subterraneous excavations.

In Derbyshire, as in Italy, the sulphate of lime, taking the form called alabaster, is worked chiefly for the artist, and the manufacture of it in the latter country forms a very important element among the industrial occupations of the people. The finest white varieties are usually selected for statues and busts; the ordinary variegated kinds are worked into pillars, and other ornaments for the internal

decoration of houses ; and the most beautiful variegated sorts are cut into vases, columns, plates, and other drawing-room furniture of an ornamental kind. The neighbourhood of Volterra, in Tuscany, contains so great an abundance of this substance as to supply alabaster to most parts of the world. The beds there containing it belong to the Tertiary period, and salt-springs abound in the vicinity of the quarries.

## ALUM-WORKS.

ALUM is a mineral greatly used in the arts, (in the manufacture of leather, paper, &c., and in various processes of dying,) and it occasionally appears in a native state as an efflorescence on the surface of bituminous shale, and various kinds of stones, shales, and earths, which are for that reason called alum-shale, alum-stone, alum-earth, &c. These rocks usually contain only the constituent parts of alum, and not the mineral itself ; but the constituent parts are greatly disposed to unite, when placed in juxtaposition. It is the object of alum-works to arrange the materials, so that the most favourable circumstances for the formation of the mineral shall be presented ; and a little geological as well as chemical knowledge is necessary, in order to do this to the best advantage.

The alum of commerce is a compound salt of alumina and potash (a bi-sulphuret), and therefore requires the presence of its two bases, and some sulphate or sulphuret, which is most usually the sulphuret of iron or iron pyrites. Wherever all these substances are present, and in such a way that the alteration in the combinations can be readily effected, there alum-works may be established. The most ancient and most celebrated alum-works are

those of Rocca (the present Edessa), in Syria ; and hence the alum of commerce is often called *Rocca*, or *Rock-alum*. A sulphate of alumina and potash was afterwards discovered among the volcanic rocks of Italy, and from this alum-stone the mineral was for a long time chiefly obtained ; but it is now manufactured yet more extensively in our own country and in Germany.

The shaly beds containing pyrites, which are found in the upper part of the Lias formation in the north-east of England, have been found extremely convenient for the manufacture of alum, and are commonly called alum-shales. A section of the lias is exposed on the sea-coast of Yorkshire, near Whitby, and exhibits an extensive range of lofty cliffs, from three to four hundred feet in height. These cliffs are composed of very dark grey beds of slaty clay, lying nearly horizontal, and stretching out at the base into an extensive flat pavement, on which the sea washes, and which is laid bare to a considerable distance at low water. Mingled with this clay is a large quantity of iron pyrites, which is sometimes so abundant, that spontaneous combustion takes place when the beds are exposed to atmospheric action. The clay itself is of a silky lustre, and splits very readily into thin laminæ, but is sometimes extremely hard when dry. A considerable quantity of *jet*, which is a peculiar and well-known form of carbon, is found in the shaly beds, and in some parts they are also extremely fossiliferous.

The tertiary beds, abounding with lignite, found on the banks of the Rhine, near Bonn, also contain alum-earth, but in a somewhat different condition. In this case, the lignite is remarkable for the quantity of iron pyrites accompanying it, while the associated clays consist of nearly pure alumina. The mixture of sulphuric acid, alumina, and potash is obtained by burning together the pyritous wood

and the aluminous earth. A double decomposition takes place during the combustion, the iron is left in the shape of oxide, and the double sulphur-salt of alumina and potash is produced. The burnt ashes being soaked in water, the alum is dissolved ; and the water being evaporated, and the residuum re-dissolved and evaporated several times, the salt is obtained sufficiently pure. It is then allowed to crystallize in tubs, and is in a fit state for transportation.

The process pursued at Whitby is nearly similar. The shale (sulphate of alumina, containing potash and pyrites) is roasted until the sulphur of the pyrites combines with the alumina and potash, and forms a soluble salt, the iron combining with oxygen, and the other impurities being, for the most part, insoluble. The resulting salt is then made to undergo successive solutions and evaporations, till it is sufficiently pure for the purposes for which it is required. About 1500 tons are annually prepared at Whitby, and the estimated value is upwards of 30,000*l*.

Native alum is sometimes found, but not in sufficient quantities to be worth working for commercial purposes.

#### LIGNITE, OR BROWN-COAL.

THE beds of carbonaceous matter that occur in the Secondary or Tertiary formations in England are rarely of sufficient importance to be worth extracting, and the mining operations that refer to them possess little comparative interest. There are, however, some localities on the Continent of Europe where these imperfect beds of coal, called lignite, or occasionally *Braun-kohl* (brown coal), offer the only fuel at hand, in districts where wood is expensive, and in these places they have been somewhat extensively worked.

Still even in England, in the south-western part of our island, and before the Welsh and Staffordshire coal was sent into the market, there have been in former times some rather extensive mining operations for this imperfect carbonaceous matter, although, of course, on a far more limited scale than those alluded to in the chapter on coal-mining. The Bovey coal, a tertiary deposit, lying unconformably on the beds of the Cretaceous period, in the east of Devonshire; the Kimmeridge coal, a singular bed, perhaps not entirely of vegetable origin, formerly worked near Kimmeridge, in the clay of that name, on the coast of Dorsetshire; and also the oolitic coal of Brora, already described, have all attracted attention, and have led to the undertaking of many abortive attempts, in order, if possible, to render valuable these imperfect and non-bituminous carbonaceous masses, which can never enter into competition with the produce of the numerous and rich coal-fields of Britain.

Of all these, the Bovey and the Brora coals are those of greatest importance. The former was worked extensively at the close of the last century; and, in an account given of it in 1797, it is described as being from four to sixteen feet in thickness, alternating with clay, and obtained from pits about eighty feet deep. At that time it was used in a neighbouring pottery; and the state of the works appears to be the same at the present day, with the exception of additional excavations that have been made. This lignite emits an offensive smell when burnt, which prevents it from being employed for domestic purposes, except among the lowest cottagers.

In some parts of Germany near the Rhine, and in the valley of Switzerland not far from Lausanne, the lignites are both more extensive and more valuable than in our

own country. In both these localities, and elsewhere on the Continent, they occur in strata of the Tertiary period and of fresh-water origin, and in the absence of better, or to save more expensive fuel, are used to a considerable extent, though chiefly among the lower classes.

The brown coal of Nassau occupies a rather singular position, in many cases immediately overlying a great tabular expanse of basalt, which caps strata of the Newer Tertiary period. The coal consists for the most part of the trunks of trees of large size; it is quite black in the mine, but dries of a brown colour, and it often exhibits distinct marks of woody structure, even allowing portions to be used in shoring up the roof of the mine. It exhibits, however, a gradual transition in different parts of the same mine, occasionally passing into a completely carbonised and even partly bituminous state. The bed is sometimes more than ten feet thick, and is parted by thin seams of clay; it is worked by a level coming out on the hill side, but there is no reason to believe that it is continuous, rather consisting of patches lying at a considerable elevation on the hills. It is horizontally bedded and undisturbed, but the uneven surface of the basalt on which it rests frequently makes it appear as if it had been dislocated subsequently to deposition.

#### QUARRIES, AND OPEN WORKINGS.

EXCAVATIONS of whatever kind, although not perhaps immediately dependant on mining principles, possess too much in common with them, and have too great reference to the modes of operation they involve, to be out of place in this chapter. I proceed, accordingly, to describe them, so far as they belong to practical Geology.



Slate is a substance so extensively used, and so peculiar in its structure, as to deserve the first place in an account of quarried minerals; but the nature of slaty cleavage has been already discussed in a former Chapter, and need not detain us now. It is sufficient for my present purpose, that the reader should know what is commonly understood by the word slate, and the geological and mineralogical characters which distinguish it.

The principal slates of the British Islands are found in Cornwall, North Wales, Cumberland, and various parts of Scotland. Of these, the Cornish slates are some of them extremely beautiful and durable, and those of Delabole, a well-known locality, combine lightness with considerable strength, and have been long celebrated. "Borlase, in 1758, states, 'that for its lightness and enduring of weather, it is generally preferred to any slate in Great Britain.' He describes the great quarry as being in his time 300 yards long, 100 wide, and 80 deep; observing that 'all the slate is carried, and with no small danger, on men's backs, which are guarded from the weight by a kind of leathern apron or cushion.' The mode of working this quarry is, as may readily be supposed, much improved at present; and the slates in the rough are raised by a whim to the top, whence, after being finally split and shaped, they are carried away by carts and waggons."\* Besides this, there are other quarries of good slate near Tintagel, and many in other parts of the district, but not of so good a quality. The slate is in all cases detached from the rock by blasting.

Very large and valuable quarries of good slate are worked at Balahulish or Balachelish, in the most northern

\* De la Beche's Report, &c., p. 503.

part of the county of Argyle, in Scotland, on the side of a mountain rising immediately out of Loch Leven.

In these quarries, which have been opened only since the year 1760, the slate is exposed on the mountain side, its cleavage planes making an angle of  $80^{\circ}$  with the horizon; and, commencing on the shore, the quarries extend southwards along the side of the mountain. The face of the rock is laid open by workings, three in number, fronting the west, and rising one above another in successive step-like terraces, all of them being entered from the north end of the bed; the height from the lowest terrace to the top of the workings is about 216 feet, and the face of the rock wrought about 536 feet. The first level enters from the high road, 28 feet above high-water mark; the second is 66 feet above the first, and communicates directly with the sea by an arch thrown over the high road. The third is 74 feet above the level of the second, and is worked to the height of 76 feet, its produce being conveyed down an inclined plane to the level of the second.

The Balahulish quarries are very conveniently situated, both the drainage and the waste and broken slate being at once got rid of into the sea. The annual produce some years ago was from five to seven millions of roofing slates, weighing about 10,000 tons; and as in slate quarrying there is at least six times as much broken slate and other solid matter in the condition of rubbish as there is of saleable produce, the advantage of the position of these quarries is at once manifest.

But the quarries at Penrhyn, near Bangor, in North Wales, are beyond comparison the most important both in respect of the extent of the works, and the quantity of slate annually quarried and exported from them. In these vast excavations, which have also the advantage of

proximity to the sea, there are no fewer than ten levels, rising one above another to an enormous height, and the slate, when shaped, is carried down at once by a railroad on board the numerous vessels constantly waiting to be loaded. The number of persons employed in these works is upwards of 2000, and the property is said to yield to the proprietors from 30,000*l.* to 40,000*l.* per annum.

The slates of Cumberland and the lake district, although some of them sufficiently important, are not quarried to any considerable extent for exportation. Near Kirby Ireleth, however, there is an excellent dark-coloured roofing-slate, which has been long worked, and fine beds of dark-coloured flagstones have also been obtained from the lower members of the same group. The igneous rocks protruded through the new red sandstone in Charnwood Forest, in Leicestershire, have also brought up some fine roofing-slates, very valuable in that district, and very extensively worked.

In all these cases the slates are not more recent than the Middle Palæozoic period, nor is there any instance in England of true slates of a more modern date. In the Alps, however, the causes producing this peculiar mineral structure have affected clays of the Secondary period; and even of the Cretaceous series, the most modern of all the Secondary rocks. It is, however, rarely that this is the case, and for the most part the slates are confined to the old rocks, and seem to indicate an amount of change not producible, except under circumstances extremely different from those which obtain near the earth's surface.

Besides the true slates, flagstones of a peculiar kind, and more or less fissile, are frequently met with, and are occasionally quarried to supply the place of slate, and they

sometimes even bear the same name, although they possess none of the peculiar characteristics of that substance. The 'Stonesfield' and the 'Colley Weston' slates are instances of this, the rock in each case being a limestone, which splits readily into thin laminæ. Other slabs of fissile stone, called tile-stones, are found in some of the rocks of the Palæozoic period, and, as well as flagstones, (also fissile beds of sandstone or limestone,) are occasionally quarried to some extent.

Quarries of stone for building purposes will come under consideration in a future Chapter, when speaking of the application of Geology to Architecture, and it is therefore unnecessary now to allude to the subject.

It sometimes, though rarely, happens that metallic ores and coal are obtained by the simple process of quarrying, and without extended mining operations. Some of these instances have been already alluded to; but it may be worth while to mention here, as among the most remarkable, and also as not having been hitherto noticed, the apparently inexhaustible mines of iron in the Isle of Elba, a considerable number of the rich iron mines of Sweden, and, in former times, the well-known copper mines of Fahlun, also in Sweden.

The shape of the vein, its position and the nature of the section exhibited, the changes in its form, and the indications which have caused a greater extent of working in some directions than in others, give very different and singular appearances to the workings which are thus exposed. The Fahlun mines, which are open on the line of intersection of the vein with the surface, offer the appearance of an immense dyke, long and narrow, having a depth of near eighty yards, and the walls being always steep, sometimes vertical, and occasionally overhanging.

The remarkable mine of Rio, in the Isle of Elba, is another instance of an open working, situated half way down a steep escarpment which terminates in the sea. The vein has been divided by horizontal terraces into five parts, each from ten to fifteen yards high, and thirty to sixty yards long. The vertical faces of these step-like portions have afterwards been excavated where the richer parts of the vein appeared, and are cut into other steps of more convenient proportions. The successive terraces are connected by slopes, which allow the passage of carts and wagons to carry away the produce.

## CHINA-CLAY.

AMONG those open workings which come under our consideration in the present chapter, I must not omit to include a singular vein of china-clay worked in Cornwall, and forming there an object of considerable commercial importance. This clay is derived from the decomposition of the felspar, which forms a component part of the granite of the district, but that which is obtained from the vein is by no means the only source of the supply.

The greater part of the china-clay exported from Cornwall is, however, artificially prepared from granite, by washing the decomposed rock in such a manner, that while passing through a series of tanks the heavier and useless particles fall from the water in which they have been held mechanically suspended, but the finer particles, composed of the remains of the decomposed felspar, are carried onwards, and allowed quietly to settle in other tanks. The water being removed from these, and the sediment partially dried, the latter is afterwards con-

veyed to proper houses, where the drying is completed.

In a district of decomposed granite, such as much of the eastern part of the Austell mass, those places are selected for works of this kind in which the rock contains as little mineral matter as possible, except that formed from the decomposition of the felspar, and where water can be turned on conveniently. The decomposed rock, usually containing much quartz, is exposed on an inclined plane to a fall of a few feet of water which washes it down to a trench, whence it is conducted to the catch-pits. The quartz and other impure particles are in a great measure retained in the first catch-pit, but there is generally a second or even third pit, in which the grosser particles are collected before the water charged with the finer particles of the clay is allowed to come to rest in the larger tanks or *ponds*. Here the china-clay sediment is allowed to settle, the supernatant water being withdrawn as it becomes clear by means of plug-holes in the side of the tank. By repeating this process, the tanks become sufficiently full of clay to be drained of all water, and the clay is allowed to dry so much as to be cut into cubical or prismatic masses of about nine inches or one foot sides, which are carried to a roofed building through which the air can freely pass, and where the cubical or prismatic lumps are so arranged as to be dried completely for the market. When considered properly dry, the out-sides of the lumps are carefully scraped, and exported to the potteries either in bulk or in casks.”\* Sir H. De la Beche adds, that between seven and eight thousand tons of this artificial china-clay are annually exported from Cornwall and Devon.

\* Report, &c., on Cornwall, Devon, and West Somerset, p. 508.

Independently of the artificial china-clay, the district furnishes about 25,000 tons annually of a natural china-clay, formed, it would appear, much in the same manner as is now done artificially, the decomposed granite having been washed down from Dartmoor into a lake or estuary ; so that while the grosser particles were first lodged at its higher end, the fine sediment was accumulated at the lower part. This material is dug from pits excavated through the surface gravel, and being thrown from stage to stage, according to the depth, till it reaches the surface, is then carried to the clay cellars and properly dried.

It appears, on the whole, that 37,500 tons of mineral matter (including the china-stone, or unprepared clay,) are annually shipped from the south-west of England to the potteries, and the value of this export must amount to nearly 50,000*l*. A century ago, it does not seem that any part of it was made use of, or that this important produce was then of any value whatever.

I have now completed my account of the principal economic uses to which the various materials of the earth's crust have been put, in the cases where those substances required the application of some degree of ingenuity to extract them. It is worth while here to pause a moment, and look back upon this list of mining processes and the application of mining principles, in order to note how far the subjects of the last few chapters have reference to the general nature of Geological science.

In the first place, it will be evident that Geology, having for its object "to observe and describe the structure of the external crust of the globe," every addition that is made to our knowledge of that structure, is a direct gain to Geology ; and that, on the other hand, every ad-

vance made in Geological science, and in arranging and determining the general principles and laws by which the earth has arrived at its present condition, must ultimately tend to the attainment of sound conclusions on the objects before us, and the facts presented to our view in the contemplation of Nature. In other words, as every fresh observation renders our power of correct generalisation greater and more complete, so every generalisation attained, every law discovered, every sound theory founded upon facts and careful observations, is a direct practical benefit.

In the next place, I would remind the reader, that as in the Chapters on Descriptive Geology I assumed his acquaintance with the main facts of Geology, now clearly determined, such as the stratification and disturbance of rocks, a fixed order in their superposition, and the like; so he has in these latter chapters been called upon to exercise the knowledge he has acquired, while at the same time the facts recorded are in every case additional proofs of the general truth of the conclusions. Thus, in the discussions concerning mineral veins, their nature, the circumstances under which they became filled with metallic ore, the localities in which they occur, &c.; and in the description of the seams of coal or of iron ore, and the beds of salt, &c., I have made a reference to the general conclusions to which Geologists have arrived, but the additional facts adduced in order to explain the subject all tend in a greater or less degree to bear out those conclusions.

And here, again, I may remark, that the relation of Geological science with the most practical of the industrial employments to which I have hitherto had occasion to allude, is strictly mutual, so that the one cannot advance without benefiting the other. The observations of the man



who is merely anxious to advance the interests of his employers, or his own interests, in a mining operation of any kind, are necessarily those which, if he records them properly, are the most useful and valuable in the ultimate determination of disputed points in science. The application of these observations, on the other hand, and the working them up into general laws, is the method by which the scientific man, who is also practical, repays a hundredfold to his fellow workman, the labour and expense of these records of phenomena.

The subjoined vignette (representing a locality on the coast of Ireland) does not bear any special reference to the subjects treated of in this chapter, but it is an interesting example of stratification, exhibited on a grand scale in a sea cliff, and laid bare by the action of the waves.



KILLEN DUFF

## CHAPTER X.

MINING RECORDS. — LAWS OF MINING IN GERMANY AND ELSEWHERE. — THE NATURE OF THE RECORDS REQUIRED, AND THE IMPORTANCE OF PRESERVING THEM IN A PUBLIC OFFICE.

HOWEVER comparatively unimportant it might seem to the advance of Geology as an abstract science, that there should be a public and secure place for the deposit of documents relating to underground operations, there are, perhaps, few results more likely to be of permanent benefit to the country, and none more certain to establish upon a firm basis systems of observations which may hereafter be the groundwork of extensive and important generalisations, than the preservation of all documents relating to mining, whether conducted in mineral veins, or in beds of coal. Fully impressed with the necessity that there is of bringing into one place, and reducing to a system, such documents, and anxious to induce every practical man who may read these pages to assist in this great work, I have determined to devote the present chapter to a consideration of the subject, and to point out, so far as I am able, the nature of the mining records which are most necessary, and most likely to be generally useful.

It is also greatly to be desired that this subject should at the present moment be put so prominently forth as to attract general attention, because the Government of our

country has exhibited an interest in the matter, by providing a depository for such documents in the "Mining Record Office," properly associated with the Museum of Economic Geology, concerning which I have before spoken.

The advantage to be derived from bringing together a collection of plans and drawings of the works that have been excavated in mines at any given period, and the details of the workings, must necessarily be very great, both in regulating and giving accurate data for the establishment of Geological theory, and also with reference to the phenomena of Descriptive Geology; while considered with regard to future mining operations, the value of such plans is even greater. Not only will the positions of all old workings be then known, so that they may be avoided, but much direct information will be conveyed as to the prospect that may exist of a successful result in doubtful cases.

Perhaps the most effectual method of giving to the English reader an idea of the nature of mining records, will be to preface the recommendations I shall offer on that head, by a short account of the legislative enactments in those parts of Europe where mining has been for a long time so principal an employment, as to have called for special laws, and a separate system of jurisprudence. The mining districts of Saxony, and of the Hartz, are those of greatest interest in this respect.

In the Hartz, the general system of laws in common use was established so long ago as in 1593, and is divided into three parts, namely, that which has reference to the officers employed in the mines, that which relates to the mines themselves, the galleries, and methods of working, and that which treats of the methods of reducing the ore. Of these, the first, although not without interest with respect to our own mining customs, is hardly so important as to

require that any detail should be given here of its enactments; and the third I have already alluded to sufficiently in a former chapter. It is chiefly the second that belongs to the subject of mining records now under consideration.

In the constitution by which the Hartz mines are governed, there are not less than one hundred and two articles which refer to the manner in which the mines are to be worked, and these are arranged under several heads. The conduct of the superintendant and other officers, the arrangement of the working hours, the duties payable to Government, the extent of the jurisdiction of the various officers, and many other matters of internal policy, are all amongst the subjects of legislative enactment, and concerning many of these, also, but little interest would be felt in this country. There are other arrangements, however, of more general importance.

The first article in the code is one which gives a conditional right of property to the discoverer of a metallic vein, without any interference being allowed on the part of the proprietor of the land on which the vein is discovered.

The second article provides, that the superintendant of the mines in the district, shall have the power of conceding grants, with respect to all kinds of mineral veins whatever, the person claiming the grant specifying the extent of his discovery, and the exact site. This grant is given for a very trifling fee, and cannot be refused to the first discoverer of a vein.

Succeeding articles provide, that within a fortnight of the grant being conceded, the vein must be laid open in such a manner, that the superintendant of the mines can examine it, and that this examination having taken place

the grant must be confirmed, as it otherwise lapses, and becomes null. If, however, difficulties should arise, rendering it expedient to postpone the confirmation of the grant, the superintendant of the mines has it in his power to do so within certain defined limits. The right to the mines being confirmed, the discoverer is obliged to proceed with the work, employing at least four hours each day in working his newly found vein.

The ninth article has reference to the important subject of registration, and it requires, in the first place, that all the books and registers of the work done in the mines be safely preserved in a chest, of which the superintendant of the mines, and the secretary of the mining district, have each a key, and these books must always be produced on the application of any person concerned in the workings. The following is a list of the books and registers to be preserved.

I. *A register of the grants conceded.* In this is entered a list of all the companies and individuals who have worked the mines, the specifications of the grants conceded by the superintendant of the mines, the extent of the grants, and the nature of the work done.

II. *A register of the mines in which the work is suspended.* In this register an account is preserved of every mine in which the works have been from any cause suspended; of the reasons for suspending the work, whether from want of water for the water-wheels, &c., or otherwise; the prospects that there are of the work being carried on again; and the reasons why it should not be considered free, and granted to other adventurers. In this book also are registered the rights of the mine with regard to water-courses, as they have been regulated by the master of the mine and the inspectors.\*

\* The machinery used in most of the German mines was formerly almost en-

III. *An agreement-book*, in which all decisions and arrangements with respect to disputes or differences that have arisen between adventurers are registered, with a statement of the circumstances attending the difference.

IV. *A contract-book*, in which the accounts of each mine are kept, the expenses of working, the price of the work, the produce of the mine per quarter in silver, lead, copper, &c., the debts of the mine, and the quantity of ore that has been brought to the surface and not reduced.

V. *A report-book*, in which are preserved the reports of the captain of the mines and the viewers on the actual state of each mine, and the intentions that have been resolved on concerning it.

The tenth and three subsequent articles of the code refer to the powers and duties of those who have received a grant of a mine that had been before worked, and direct that the workings shall be carried on under the direction, and with the concurrence, of the superintendant of the mines, and according to a certain plan, a share of the adventure being always reserved for the sovereign.

The officers to be employed in the mines, their titles and pay, the powers they shall possess, and the manner of their appointment are next provided for; and there then follow some curious regulations with regard to the working of new veins or ores found in the progress of the mining operations. These all exhibit very strikingly the right reserved to the crown of claiming the whole of the underground property, and therefore exercising the most complete and absolute direction and control over its management. It is not necessary to dwell on these points, or on the extent of the

tirely, and is still to a great extent, worked by water-power. It is for this reason that such careful provision is made with regard to the surface-streams.

concession made to an individual or company, and the powers they possess of extending their works.

Most of the remaining articles have reference to the magnitude and extent of the galleries and shafts, and the circumstances under which they may be carried on and enlarged by the adventurers.

However limited the power of the adventurer may seem to be under these regulations, the case was not very different in our own country with respect to the mines of Cornwall, which have been the subjects of special legislation, first in the year 1201, when a charter was granted by King John, and afterwards in the beginning of the next century, under Edward the First. It was not, however, till the reign of James the First that a regular code was established, and the mining regulations actually made binding. At that time, unfortunately, no mining records were insisted on, and no attempt was made to register the accounts of the different mines, so that in this respect England has been greatly behind her continental rivals.

The mining district of Derbyshire was formerly a royal domain, and was governed by a code of laws, some of which were sufficiently arbitrary and singular; but here also no mention is made of preserving the plans and other records of the different mines, which have accordingly been worked with great irregularity, and often with little regard to real and proper economy.

The code of laws by which the working of the mines of Saxony is governed, resembles that already described as regulating the Hartz district, in many of its more important provisions. The Bergmeister, or superintendant of the mines, is a public officer appointed by Government to control all the mines of the district, and it is his duty to grant concessions such as those given in the Hartz. Every prac-

tical facility is given to encourage a steady working of the mines, and every effort made to have them worked to the greatest advantage. The records preserved are, on the whole, almost as extensive as is needed, and are always to be referred to by those interested in the workings; and there is one point especially attended to, which in our own country has been most shamefully neglected, I mean the preserving a great formality in closing a mine, and handing down a minute account of the condition of the mine when it ceased to be worked. The following are the directions with reference to this point :—

When a mine is to be abandoned, the superintendant of the mines and the inspectors (officers appointed to inspect the mines from time to time in succession, throughout the district, and report on their condition) visit the works, detach portions of the ore, if any is to be obtained, assay it, note its condition and value, and mark down these observations on a ticket which they attach to the specimen, and which it is their duty carefully to preserve. They register in a book, kept for the purpose, all the circumstances which have led to the abandonment of the mine, mentioning the magnitude of the vein, the hardness of the rock, the proportion of ore it contains, the depth of the workings, the nature, direction, and magnitude of the galleries, and the distance to which each has been carried. It is not allowed that the persons abandoning the mine carry away that part of the machinery and apparatus attached by nails and iron clamps, nor may they remove the rubbish, nor even the ore that has not been washed, the refuse from the washings and siftings, and the unpicked ore. Even if these things have been sold, the sale, being illegal, is declared void, and only such matters can be removed as have been purchased by the adventurers themselves,—for instance, tools, and ore that has been fairly extracted.



If some of these provisions might seem incompatible with English habits, and the rights of property as they exist amongst us, the principle at least might be obligatory; and no proprietor should be allowed to leave underground works in an imperfect, unfinished, or dangerous state, or without such distinct indications of the actual condition of the works as may guard those who may succeed them from the fearful accidents that have occasionally resulted from coming suddenly and unexpectedly upon extensive and neglected workings. To see that such notice is given as may serve to warn the future proprietor of an imminent danger, is surely a duty incumbent on Government, and one which loudly calls for legislative enactment in England.

With regard to mining records generally, perhaps the following are those most important to be attended to, and copies of them should be preserved in some public place, with respect to every mineral vein worked in the country.

I. Accurate underground plans of the works on each level, and vertical sections through every vein and cross-course worked in the mine. To these plans should be attached notes referring to every fault and slip met with, its amount, direction, and effect on the vein, and the changes occurring from time to time in the vein, on passing into new ground, or traversing a dyke.

II. With regard to the veins themselves.

A. *The exterior relations of the vein.*

1. Its position, viz.: its distance from known points, its direction, and its inclination.
2. Its magnitude, viz.: its length and width at various points, the manner in which it terminates, and the way in which it ramifies.

B. *The internal state of the veins.*

1. The predominating ores and veinstones, and the

order in which they are found in relation to one another.

2. The other ores and veinstones, and the circumstances under which they also occur, their frequency, size, richness, and the places where they are found.
3. The remaining internal circumstances of the vein; the fragments of rock found mixed with the substance of the vein; the mechanical condition of the filling up of the vein; the walls which separate it from the adjacent rock; and the nature of its adherence to the rock.

c. *With regard to the adjacent rock.*

1. Its nature and its Geological relations with the vein.
2. The inclination of the strata, if the rock is stratified, and the predominating joints and divisional planes.
3. The condition of the rock near the vein, and the greater or less amount of decomposition it has suffered; a statement of the metallic particles with which it is impregnated, and the fractures it has undergone.
4. The effect of the surrounding rock upon the vein, as well as that of the vein upon it.

d. *The relation of the vein under consideration with the other veins which it meets, and reciprocally.*

1. The direction and inclination of the veins at the point of meeting, the nature of the ores and veinstones, and the change, if any, that takes place at the intersection.
2. The peculiarities presented by smaller veins, or

threads, at their intersection with the principal vein, observing the following points :

- a. If, after meeting, they continue together for some time.
- b. If the veins that meet the principal vein also cross it ; or,
- c. If they are crossed by it.
- d. If they produce ramifications, break the vein, or are broken by it ; disturb it, or have been disturbed by it ; and the magnitude of all these effects, if they have been produced.
- e. If they intercept and stop the course of the principal vein, or change it into mere threads, or are themselves intercepted by, and swallowed up in it.

*e. The principal works done in the vein.*

Under this head should be noticed the excavations, and other trial works made in new ground, whether successful or not, in finding ore, as well as all details connected with the regular workings. An account should also be given of the extent of each mining property, and the name of the proprietor.

The above intimation of the kind of information required concerning mineral veins is chiefly taken from Werner's "New Theory of the Formation of Veins," a translation of which into English was published at Edinburgh in 1809. I cannot conclude this part of the subject more appropriately than in the words of the great Saxon Geologist. He says, "Such an account of mineral repositories requires much trouble, and a considerable time, to render it complete ; but, from the very commencement, every step made in the labour will be profitable and useful of itself ; while it is only by adding, from time to time, the new observations

arising from our labour that we can hope to render it perfect. Such a description of a mining district would indeed form together a complete and instructive whole. If our ancestors had left us such documents for two centuries past, or even for half a century, of what advantage would it not have been to us? From what doubts would it not have relieved us? With what anxiety do we not turn over the leaves of ancient chronicles in search of information, often very imperfect, obscure, and uncertain? With what pleasure do we not receive the least sketch or plan of some ancient mine? With what pains do we not rake up the heaps of rubbish brought out of old excavations, to discover pieces which may afford us some idea of the substances which were formerly worked out? Yet between these documents and those which we might obtain in the way pointed out in the preceding paragraphs, there is as much difference as between night and day. Ought it not to be an obligation and a duty, for us to collect and leave to future generations as much instruction and knowledge as possible on the labours carried on in our mines, whether it be in those that are still worked, or in those which have been given up.”\*

But it is no less necessary that mining records should be preserved of those districts worked for coal and other mineral produce obtained from seams and beds, than that an account should be kept of mineral veins. I may quote the authority of the late Mr. Buddle, with reference to this subject, and in testimony that “the inconvenience and unnecessary expense which have frequently been occasioned in the Newcastle and other coal-fields, as well as the many fatal accidents which have happened from the want

\* Werner's “New Theory of the Formation of Veins,” translated by Dr. Anderson, p. 205.

of accurate plans and records of the former workings of exhausted or relinquished collieries, have long been a subject of public regret, as well as of individual loss and suffering.”\*

It is greatly to be desired that this neglect in preserving documents, and in accurately recording the condition and extent of the workings in every mine, should be remedied; and even so long ago as the close of the last century, an attempt was made, which was again repeated in 1815, but on both occasions the endeavours to excite due attention proved abortive, partly, it would appear, from there being no suitable place in which to collect and deposit the requisite information and documents for effecting this desirable object.

Mr. Buddle, in the paper above quoted, (dated 1834,) has proposed to set apart a division of the Museum of the Northumberland Natural History Society, for preserving these records, and the advantage of their being retained on the spot for future reference is too evident and considerable to allow any one to question the reasonableness of this plan. It might, perhaps, be advisable, that in every district there should be some such local record office, but, at the same time, copies of all the documents might be forwarded to the Mining Record Office in London, where a proper official person would have the charge of them, and where they would be preserved with that care which their importance demands.

The nature of the records, and the information which it is suggested by Mr. Buddle they might include, may be arranged under the following heads.†

\* Transactions of the Natural History Society of Northumberland, vol. ii. p. 309.

† Transactions, &c. *ante cit.* p. 310.

1. The name of the proprietor of the surface and minerals.

2. The locality and extent of the property.

3. The number and description of the seams of coal and other minerals which it contains.

4. The thickness and quality of the several seams of coal; which of them have been worked; to what extent they have been worked; and why the working of any of them has been discontinued, or not commenced.

5. The winning of the colliery, viz.:—The number and position of the shafts; the difficulties met with in sinking, and the method of overcoming those difficulties.

6. The system of working; whether by pillars, by the long method, by pannel work, or in what other way.

7. The dip and rise of the colliery. Description of the dykes, &c.

8. An account of the accidents that have happened by explosion.

9. The other accidents that have happened in the colliery, with their causes.

10. The system of ventilation practised.

11. General observations.

To these may be added, in those districts where the ores of iron are bedded with the coal, an account (1) of the number, thickness, position, and extent of the seams of iron ore; (2) their relative value, and the per centage of metal obtained from them; and (3), The manner in which they have been worked, whether subordinately to the coal, or as a principal mineral product. Besides this, very particular attention should be paid to the preservation of accurate plans of discontinued workings, with such references as may render it impossible to mistake the localities to which these plans refer. This latter is the more necessary,

since up to the present time, and even in cases where reports of the state of the underground workings have been preserved, they have often been found useless, owing to the impossibility of identifying the pits. This inconvenience was very strikingly exhibited in the drowning of the Hetton colliery in 1815, the water breaking in from workings which had not been relinquished more than seventy years. It should be very carefully noted in the description of relinquished workings, whether the pits are filled up, or only scaffolded; and if the latter, at what depth. The compass bearings of all the workings should also be laid down, and the amount of magnetic variation recorded, that at any future time the accurate position of the underground excavations might be understood and ascertained at once from the plan.

It should also be remembered, that those who are desirous of assisting in this important work, "should not be deterred from giving very full and detailed accounts from the apprehension of being considered too prolix and tedious, as on such a subject it is more excusable to say too much than too little."\*

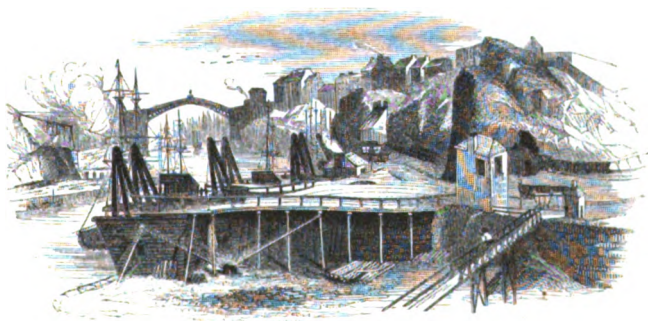
I am unwilling to conclude this Chapter, without once more endeavouring to impress upon the reader the very great importance of the subject, with respect to the future progress of mining in this country. The more extensive our mining operations are, and the more they surpass those of other nations, so much the more necessary is it that such a knowledge of them should be preserved and handed down, as may guide those who succeed us to the most probable localities for obtaining what remains of our mineral treasures. Nor is such a knowledge less important as a warn-

\* Mr. Buddle's paper in the Transactions of the Northumberland Natural History Society, *ante cit.* p. 336.

ing to turn away the fearful risk of coming unexpectedly upon some neglected and forgotten excavation, whence may issue a torrent of water, inundating the works, and drowning those employed in them ; or a rush of foul and explosive gas, yet more destructive, if possible, to life and property, and yet more instantaneous and resistless in its course.

There can be no real excuse for the neglect of which such accidents are the terrible result, and it is a duty imperative on every one to do all in his power to remove the disgrace, and the extreme inhumanity, of that carelessness in the management of mining property in England, from which these accidents necessarily follow.

The vignette represents an ingenious contrivance for shipping coal at once from the waggons in which it is brought to the pit mouth. These waggons are conveyed by a tram-road to the port, and descend by their own weight into the vessel, where they discharge their load, the empty waggon being lifted to the tram again by a counterpoise.



DROPS, AT SUNDERLAND.



## CHAPTER XI.

ON THE APPLICATION OF GEOLOGY TO ENGINEERING AND ARCHITECTURE.—ROAD AND CANAL MAKING :—THE CONSTRUCTION OF HARBOURS, BREAKWATERS, QUAYS, AND BRIDGES.—RAILWAY SECTIONS.

IF it is desirable that those persons who are employed in mines and other excavations beneath the earth's surface, should be acquainted with the facts and conclusions arrived at by the study of Geology, it is no less important that the Engineer and the Architect should possess information of the same kind, for upon them devolves the management of great public works, and the construction of buildings, which should in all cases be as durable and as perfect as possible.

The different heads under which we may consider the application of Geology to Engineering and Architecture are the following: (1) The making of roads and canals, under which head is included tunnelling and embankments; (2) The construction of harbours, breakwaters, quays, and bridges; (3) The selection of sites for public buildings; and (4), The selection of building materials. Each of these subjects is well worthy of separate and detailed consideration, and each of them has immediate reference to Geology, in the strictest sense.

### I. ROAD-MAKING AND CANALS.

With regard to this subject there are two points in which the application of Geology is both immediate and

evident. These are (1), The selection of the line along which the road or canal is to be carried, and the management of the cuttings and embankments that may be determined on; and (2), The selection of the materials for their construction. I can only point out the nature of the application under the most obvious circumstances, and shall do so as briefly as possible in every case.

*1. The selection of the line for a road or canal, and the management of the cuttings and embankments.*

Although the selection of a line, whether for a railroad, a common road, or a canal, is a matter that must be influenced by many considerations, which may render it necessary to depart from that direction suggested by the structure of the country and possessing the most obvious physical advantages, it is certain, that as to make use of these should always be a great object, and as it is the duty of the Engineer to mark out the line most truly economical and the best under all the circumstances, it is not a little necessary that he should know beforehand something of the Geological structure of the district he is about to decide on.

In the case of a railroad, more than ordinary care and attention is often required to enable the engineer to decide how far he may safely, and with justice to his employers, contemplate the overcoming of natural difficulties in a country to be passed over, in order to escape from other difficulties of a different kind, arising from the local value of property, and the arrangements that have to be made with landowners. In this respect, an acquaintance with the principles of Geology cannot fail to be exceedingly useful, as suggesting resources, the existence of which could not otherwise be guessed at, or, at least, which could

not be discovered without a minute local knowledge of the district.

For, let us suppose two engineers, the one unacquainted with the order of superposition of the strata, and ignorant even of the fact of stratification at all, in its Geological sense, and the other a practical and well-informed student of Geology. And let us assume these two men to be required to construct a line of railroad from London to Dover. The mere engineer, having no knowledge of Geology, would only be aware, in a general way, that between London and the Weald of Kent, there was a range of chalk hills, (the North Downs,) but that afterwards the country was tolerably level, as far to the east as Folkstone. He would soon find that, with the exception of the Dart and the Mole, two rivers running into the Thames, the one at Dartford in Kent, and the other near Kingston in Surrey, there was no complete drainage across the hills, and therefore no continuous valley leading to the level country, and these two valleys would both be found ill adapted for the object in view. On further examination, partial valleys would, however, be discovered, and one of these, we may suppose, would be selected as the most convenient. The rest of the work to Folkstone would be calculated for as work of the ordinary kind, and cuttings and embankments would be made without any reference to the peculiar circumstances of the strata.

Let us now see what would be the inquiries and conclusions of the Geological engineer under similar circumstances. The line of road by Croydon is sufficiently marked out by the physical geography of the district, and need not be again referred to. Our engineer, however, having settled these preliminaries, would consider that in the course of his work he must cut through a considerable

portion of the lower part of the London Clay, which he would know beforehand to consist of sand and gravelly matter, mixed with some tenacious clay, and that he would then have to tunnel through the chalk, coming out upon the lower beds, which on examination he would find were considerably tilted towards the north. His line would thus carry him along the direction of a small disturbance transverse to that which had originally elevated the beds of chalk. Through part of this he would have to tunnel, and he would be aware that in a district like that extending along the line of the chalk hills there was little danger of meeting with hard beds, or with intruded igneous rock. The advantage of being thus able to predicate with considerable certainty as to the nature of the ground through which the road was to be cut, must be evident to every practical man, and we shall soon perceive how far such knowledge is immediately applicable. Besides this acquaintance with the condition of the chalk the Geological engineer in this case would remember that his cuttings and embankments would have to be made for the most part at right angles to the strike of the beds, but that in some cases the London Clay, having a different local dip, would be cut in a slant direction. Lastly, he would be aware that when he had crossed the chalk, and the other beds of the cretaceous group, he would come upon the Weald Clay, a bed dipping northwards, and which he would have to traverse in a westerly direction, and therefore directly on the line of strike.

Now the beds of the London basin, consisting, as they generally do, of clay alternating with occasional sands, are exceedingly dangerous when deep cuttings or tunnels are made through them, which are not properly defended. And this is the case, because the rain, washing through

and carrying away the sands where a section has been made, leaves the upper bed of clay barely balanced upon the lower, and with a slippery surface between them. The inevitable consequence of such a condition of things is, that after a short time the upper bed slips quietly down in the direction of its dip, falling upon and filling up the cutting that had been made through it. Accidents of this kind have happened too frequently not to be familiar to every engineer, and the cause is now to a certain extent generally understood; but nothing short of a knowledge of the structure of the country, or, in other words, of the principles of Geology, will enable any one effectually to avoid this danger, because it is one constantly recurring, and requiring different management, to a certain extent, for each individual case. The Geological engineer will know his danger, and will endeavour to provide against it beforehand. The mere empiricist who knows only the rule of practice on the occasion, will, perhaps, bring out at last the same, or nearly the same, result; but it will be by that most expensive and least creditable of all methods, a succession of failures.\*

The remarks that are so especially applicable to the London Clay, and the truth of which has been too frequently, and too practically illustrated, to be questioned by any one, also apply in a degree to all clayey beds, and amongst the rest to the Weald Clay. In the case of the

\* It would be interesting and exceedingly instructive to consider, with respect to their bearing upon Geology, several of the great lines of rail-road in England and elsewhere. It would be found that all of them, without exception, have reference at least as much to the Geological as to the Geographical structure of the country, and that in each, the great works in cutting and tunnelling, if they were not originally constructed on those principles advocated in the text, have been since altered, or must shortly be altered, in consequence, or in certain anticipation, of accidents. But in the outline of the subject at present offered, such a detail would be clearly out of place.

South-Eastern Railway, the Weald Clay is, on the whole, the most difficult to engineer with safety, because the cuttings, although not numerous, are nearly on the line of strike, which is the most unfavourable of all conditions, the smallest amount of resistance being offered by any natural or artificial defences in case of a tendency to slide.

The only defences, indeed, in these cases seem to be, (1) Thorough surface drainage on the line of outcrop of each bed cut through ; (2) A greater slope on the rise side of the bed than is necessary on the other or dip side ; and (3), Careful attention from time to time to see that no tendency to a slip shows itself.\*

The methods to be pursued with regard to clay cuttings, and the accidents that are incidental to them, belong as much to cuttings for ordinary roads and canals as railroads, and are applicable in many cases, when other beds than clay (such as courses of limestone) are separated by partings, which on exposure to the atmosphere, or on suffering the drainage of water through them, become slippery, and cause the upper and lower beds to lose their coherence. Even in an embankment, if the successive layers of earth are not level, an accident not unfrequently happens from the same cause, the moisture penetrating the beds, and if not loosening them under ordinary circumstances of temperature, affecting them afterwards during severe frost, when the expansion of the freezing water produces effects that can hardly be calculated, until they are unhappily seen and felt.

The advantage derived from a knowledge of Geology in engineering consists (it will now be understood) in

\* Watson's patent method of draining, by pipes inserted into the clay to a considerable distance, and ironstone-clay pipes, made with undercut apertures, are important defences in some cases. I shall allude to them again in the chapter on Drainage.

teaching the engineer how to avoid danger, or if he must be exposed to it, how to provide a remedy from the beginning. It often happens that a tendency once produced in the beds to slip, cannot afterwards be stopped, although the first step towards the mischief might have been prevented by timely application of preventive measures.

The loose kind of sandy earth, sometimes forming into a conglomerate, and sometimes passing almost into marl—which is often found in the lower part of the London Clay formation, and also in the New red Sandstone, and in some parts of the Greensand series, requires not a little patient management to allow of a cutting being safely carried through it, but in attempting this the Geological engineer will have a considerable advantage over his rival, ignorant of the nature of this science.

The slope, in such dangerous cuttings, should have some, and often a considerable reference to the dip of the bed, for however it may seem that the rain and other atmospheric agents must wash away the loose sand equally on both sides of the road, this is by no means the case in reality, and the washing will be far more rapid, and the tendency to slip down in large masses incomparably greater on the one side than on the other. The reason of this will be seen at once by a glance at the annexed diagram, for on the one side each particle that faces the slope is supported by the one behind it, but on the other it is pushed on and forced forwards by its weight.



IDEAL SECTION ACROSS A RAILWAY CUTTING.

On the one side, therefore, of such a cutting the judicious planting of grass will often be a sufficient defence even

with a steep slope, while on the other, even a stout wall will be insufficient to prevent a slip from the very first day of exposure.\* There are, indeed, very few cases in which the considerations of geological structure and relative exposure ought not so to modify the calculations of the engineer as to induce him to make a greater slope on one side than on the other of every deep cutting.

The circumstances under which tunnelling is advisable are also greatly influenced by the Geological structure of the district under consideration, and the direction along which a road or canal is to be carried must, in some cases, depend on the probability, or otherwise, of tunnels in certain directions being practicable. Hills of a particular shape, and under certain circumstances, will be suspected by the Geological engineer of having a nucleus of igneous rock, and will therefore be avoided, but in this case, as the external coating of the hill may be of moderately soft material, there is no other than a Geological indication of a condition which might greatly interfere with the completion of a contract, and check the progress of an important national undertaking. The nature of the beds, the condition of the stratification, and the number and extent of the faults in the vicinity are also matters that claim the most serious attention of the engineer, and ought to become the subject of careful consideration before any conclusion is arrived at, or any calculation made; for these cannot but influence very considerably the rate of progress and the cost of execution of any work that

\* The direction and the degree of exposure of the face of the cutting in such cases will also be important subjects of consideration. In our own country a south-west exposure is in most cases far more likely to be affected by atmospheric causes than any other; but this is not invariably the case, and may by local influences be less liable to be injured than any other.



may be undertaken.\* In short, in every operation of surface or deep draining, of cutting, tunnelling, and even of embanking, there should be constant reference to the Geological structure of the country and district ; and, therefore, a practical knowledge of the elements of Geology is required by the engineer in every important employment concerning road or canal-making in which he may be engaged.†

## 2. *The materials for the construction of roads, &c.*

Nor is a knowledge of Geological facts and conclusions less necessary in the selection of materials than in the original laying down the line of a road. This matter, indeed, simple as it may seem, is one that has been so rarely put before the public in a proper form, and has received so little attention, that it will perhaps by many persons be considered unworthy of notice as one of the important applications of Geological science. But the fact is not so, for not only does a great deal depend on the

\* In making a road, lines of springs are sometimes cut into, which may prove injurious to the road, and occasionally a hard supporting stratum may be cut away, and the road thrown upon a clayey or loose sandy foundation, requiring great but unnecessary expense in forming a hard artificial bottom. Both these accidents will be avoided or provided against if the engineer has any sufficient knowledge of Geology.

† “ In projecting lines of canal, particularly where tunnels are to be constructed, a knowledge of the geological structure of the country is not less necessary than in the case of roads. The probability of meeting with springs of water, the porous or impervious character, as regards water, of the rocks to be traversed, and the kinds of rock which will be encountered in cutting, may all in a great degree be foreseen by those who have examined the geological structure of the district. Hence good geological maps will be found of great value to those who are about to form canals. They also point out the various mineral substances which may advantageously be brought to the canal for the purposes of traffic. From a knowledge of this kind, canals have been made to pass by or through tracts of country where limestones, coal, or metals are discovered.”—De la Beche's ‘ How to Observe. Geology,’ p. 302.

original soundness of the foundation, but there cannot be a doubt that when the foundation is once laid, the material that is to form the surface should be most carefully selected, with a view to its durability under all circumstances of atmospheric change, as well as with reference to the passage of heavy weights over it.

It may be considered that the following is the order in which different kinds of stone may be arranged with respect to their qualities as road material ; the first-mentioned being those least advisable. Soft decomposable sandstone, soft limestone, limestone, hard sandstone, flint, chert, compact granitic rock, basalt, and undecomposable trappean rocks.\*

Roadstones, it will be remembered, have to resist not only friction but pressure, and they require, therefore, to be both hard and tough. For this reason, chert, though not harder, being tougher than flint, is a far better road material, and the more brittle granitic rocks are usually inferior to basalt, greenstone, and other contents of dykes often abundant in particular localities.

It will be evident therefore that the selection of the proper materials for road-making is best made by the person who adds a knowledge of Geology to his professional education. Such a person will at once know, by referring to a Geological map, where he can obtain that kind

\* "Flint makes an excellent road if due attention be paid to the size ; but from want of that attention, many of the flint roads are rough, loose, and expensive.

"Limestone, when properly prepared and applied, makes a smooth, solid road, and becomes consolidated sooner than any other material ; but from its nature it is not the most lasting.

"Whinstone is the most durable of all materials ; and wherever it is well and judiciously applied, the roads are comparatively good and cheap.

"The pebbles of Shropshire and Staffordshire are of a hard substance, and only require a prudent application to be made good road materials."—M'Adam's Remarks on the present system of Road-making. 8vo. London, 1823. Page 10.

of material which under all circumstances will be the most economical. He will be able to take advantage of any change in the rocks at the surface, and will judge of the probability of obtaining by proper search some vein or dyke filled with igneous rock that may more than repay the expense incurred in discovering and working it ; he will, at any rate, select the material which he has reason to believe will ultimately prove the most economical, and he will open quarries for this purpose with some degree of certainty, convinced that he is making a reasonable selection, not a chance speculation.

## II. HARBOURS, BREAKWATERS, QUAYS, AND BRIDGES.

The construction of such public works as harbours, quays, bridges, &c., requires a familiar acquaintance with the structure of those portions of the earth's crust which do not appear at the surface, and would seem therefore to call for some degree of Geological knowledge in the engineer who undertakes them.

In those cases in which the attacks of the sea are to be resisted and repelled by human contrivances, it must manifestly be an all-important object rather to make nature fight against herself, if one may so say, than oppose the feeble barriers of man's invention to the never-ceasing action of winds and waves ; and it is only, in fact, when circumstances are thus taken advantage of, and one series of natural operations is made to repel another, that any ultimate success can be attained. The discovery of the means in these cases must be greatly assisted by an acquaintance with the structure of the earth's crust beneath the surface.

In the case of some of these works the determination of the site is a point in which a knowledge of Geology may be useful, but this knowledge may also be applied to advantage in selecting the material to be used. It may often be observed, that the sea, although encroaching manifestly on an extensive line of coast, is apparently retiring in some particular spots on this same line. Instances in which the very consequence of that tearing and grinding away of the coast on an exposed headland serves to defend and even reclaim land in an adjoining bay, are valuable lessons to the engineer, and teach him how to arrange his forces in the contest he is about to wage with Nature, and where to place his greatest resisting power so as to produce the most effectual and most lasting shelter.

With regard to the materials to be employed it may be observed, that they are valuable almost in proportion to their specific gravity when they are to be exposed to the beating of the waves beneath the surface of the water, but that when exposed to the alternate action of air and water, they require qualities of a different kind, and must be selected accordingly. Sir H. De la Beche has remarked, that "an observer may often obtain information on this head by studying the condition of the rocks on the banks of rivers, and on the sea-shore; and Geologists are thus frequently aware of many situations where quarries for the purposes above mentioned may be advantageously opened."\*

I ought not to conclude this chapter without calling the attention of those who may be willing to avail themselves of opportunities that are afforded them, to the advantage that may be anticipated from the careful construction of

\* "How to Observe. Geology." Page 311.

Geological sections of railway cuttings and tunnellings. The formation and preservation of these profiles of the railways of the United Kingdom, was first suggested by the Geological Section of the British Association in 1840, and a grant was made in accordance with this suggestion, chiefly with a view of putting on record (before the slopes of the excavations became soiled over, and covered with vegetation,) the Geological appearances and strata developed by the various openings made through the country in the operations of modern engineering.

A large number of Geological railway sections procured by means of the active co-operation of all the officers of railway companies applied to, have been now collected at the expense of the British Association, and have been deposited in the Museum of Economic Geology ; and it is understood that similar sections will be procured of future lines of railway by the authority, and at the cost of Government. It has been well observed, with reference to these sections, that "to the practical engineer they offer a memorial of the experience of his profession, whence many a serviceable lesson for future operations may be learned, whereby difficulties and expense may be hereafter avoided and diminished, and from which valuable information may be derived for the appliance of materials in constructions, (it being one of the greatest arts of the engineer to avail himself of the most immediate natural resources, which he has to displace in one instance, and to apply them usefully in another when in juxtaposition). On the other hand, the minute variations of the strata and soil thus accurately delineated, and referred to well-defined altitudes above the general level of the sea, become of the very highest interest to the Geologist, and no less so to the mining engineer."

A large number of such sections have been finished, (as many as 151 sheets,) and sections have been prepared also for 167 miles of railroad, while numerous documents accompany them, containing, in many cases, full details of those strata that possess any extraordinary interest. The records being deposited in the Museum of Economic Geology are now open to the public, as are the other documents in the Mining Record Office, on proper application being made to the keeper.\*

\* The following is a list of the different railways of which the finished sections are prepared.

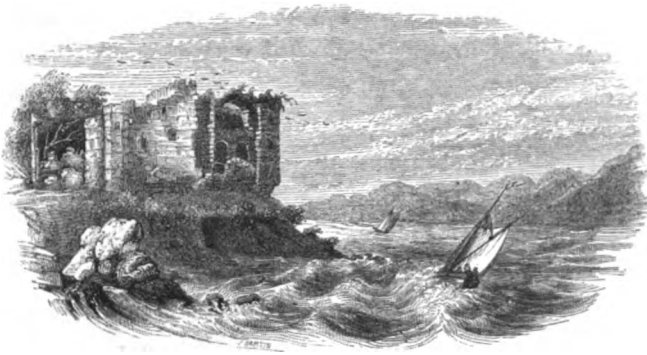
Glasgow, Paisley, and Greenock ;  
 Manchester and Leeds, Hull and Selby ;  
 Manchester, Bolton, and Preston ;  
 Bristol to Bath ;

in all 151 sheets.

Besides these, a list of blank sections of the following railways has been prepared for Geological colouring.

North Midland, Midland Counties, and North Union ;  
 Manchester and Sheffield, Manchester and Birmingham, and Manchester and Liverpool ;

in all 167 miles of railroad.



CARLINGFORD CASTLE.

## CHAPTER XII.

THE APPLICATION OF GEOLOGY TO ARCHITECTURE.—BUILDING  
SITES AND BUILDING MATERIALS.—LIMESTONES.

IN Architecture, as in all kinds of engineering works, the benefit derived from a knowledge of Geological science is shewn, not only with respect to the foundation of the building, but also in the selection of its site and the materials of which the superstructure is composed. In the case at present before us this benefit is chiefly obtained in the selection of building materials, but it also has reference to the other part of the subject, for there can be no doubt that the foundations of all buildings, more especially of those which are intended to last for centuries, should be most carefully selected, so as to possess the advantage of thorough drainage and be unaffected by any changes that may take place on the surface by the action of ordinary atmospheric causes.

It is true that of late years contrivances have been discovered by which much of the injury resulting from damp may be avoided by making use of compositions which form an artificial and water-tight base for the building; but it can hardly be too much to say, that a prudent architect would rather be dependant on natural conditions than on artificial contrivances for a subject of such great importance, and that, therefore, in every case, the

selection of a well-drained site is an object worthy of the most careful consideration.\*

It will appear from what is said in the chapter on draining, to which I must here refer the reader, that the selection of a well and naturally-drained site, and a knowledge of the means by which thorough drainage can be accomplished, are only to be attained by combining an acquaintance with the principles of Geology with professional knowledge.

It may often happen that a building is to be erected on the side of a hill, or by a river. In this case, if the dip of



the strata is towards the slope of the hill, as in the above diagram, there may be some danger lest, after particularly unfavourable seasons, the beds should slide upon one another, and tend to fall into the valley. There can evidently be no stability in a building so situated, although the cause is only apparent when we look to the Geological structure of the district.

But it is chiefly in the selection of building materials

\* No dependance can ever be placed on a building of which the foundations are not laid on thoroughly drained ground ; but a very ingenious method has been lately adopted of avoiding the evils of a slippery clay foundation by cutting a large trench below the substructure of a building and filling it in with sand well rammed. It is found that when courses of stone are laid on such a basis no settlement takes place, and it appears that this method has been successfully practised in some of the ancient buildings of Egypt.



that Geology is of importance to the Architect, and is so necessary an element in his professional education.

With regard to this subject there are two cases to be considered ; first, that in which the building is to be constructed with as great a regard to economy as is consistent with moderate durability, while in the second, the object being to construct an edifice that may be as permanent as possible, the best economy is to provide that material which is the most likely to be lasting at whatever expense of time and labour. In the first case, we have to consider what kind of stone or other material that is found in the neighbourhood is the best under all the circumstances.\* In the second it will be necessary to extend our inquiries further, and learn which of all the materials available in the country is the most durable, and the best and most truly economical under those conditions of exposure which the building is likely to suffer. The first, therefore, has reference to domestic architecture under ordinary circumstances ; the second to such public buildings as are from time to time undertaken, and which, when completed, serve as the monuments of a nation's power and wealth, and an index of the degree of advance made in the arts at the time of their erection.

With regard to house architecture of the ordinary kind, the material selected for building must necessarily be both cheap and ready at hand ; and the position of many large

\* I have been told by a practical man, who had been employed in selecting stone for an important public building about to be erected, that in looking out for good stone, he was accustomed to go to the churchyard in the neighbourhood of the quarries he wished to judge of, and examine on all sides the oldest tombstones that were there. He found that he could determine by that means the relative value and durability of most of the stones in the neighbourhood, because they were there exposed under almost all conceivable circumstances. A laminated stone, however, that might be extremely decomposable as a tombstone, would not necessarily be bad in the wall of a building, where its edges only are exposed.

cities in the vicinity of tough clay has been the cause why for all common purposes brick has been made use of instead of stone. The neighbourhood of good building material might, however, be one object of consideration in selecting the site of new cities in the colonies and elsewhere, although this of course must yield to other points of convenience or advantage.\*

Dismissing, however, the consideration of private dwellings, there are, it may be fairly asserted, scarcely any kinds of public works erected in which the selection of a building material ought not to be a very important consideration.

A stone which resists exposure to the air may be readily disintegrated by water, and on the other hand, a porous sandy rock will resist the action of water, but fall to pieces when exposed to frost and atmospheric changes. Many kinds of stone are sufficiently durable for sheltered situations, but crumble away when more exposed; others are durable in the country, becoming covered with lichens, which preserve them from atmospheric action, but are disintegrated in towns where the covering of soot they soon

\* Sir Henry De la Beche observes with reference to this subject:—"The relative facility with which good materials may be obtained in a district is, to a certain extent, marked by the appearance of the towns and villages in it, the comparative cost of obtaining them being in general better shewn by the character of the ordinary houses than by that of the public buildings and larger mansions, the stone for which may sometimes have been carried comparatively considerable distances. From the frequent practice, however, of selecting those stones which yield readily to the tool, and are hence commonly termed *Freestones*, whatever may be their other mineralogical characters, the most desirable, and, therefore, eventually the cheapest, are far from being always employed.

"Indeed, it sometimes happens that we find the common cottages built of durable materials, while the larger mansions and public buildings are not; the materials for the latter having been selected because they were readily worked up for the ornamental parts, while those from the former may have been thrown aside in the same quarry, because they yielded less freely to the tool." Report on Cornwall, Devon, and West Somerset, &c. *ante cit.* p. 485.

obtain, may assist in destroying their surface, and opening the way to a more mischievous, because a deeper-seated, action.

The necessity of a due consideration of the nature and qualities of the different building-stones in England was well illustrated by the result of a commission appointed in 1839, with reference to the selection of stone for building the New Houses of Parliament. The Report of the Commissioners contains, in a tabular form, the only published account of the nature and relative excellence of these materials, and it is, therefore, of great value in that respect to every practical man. Some of the remarks also, in the Report itself, are of considerable interest, and I shall not hesitate to make such use both of these remarks and of the tables as will best advance the object I have in view in the present chapter.

The varieties of stone that may be used for buildings may be classed under four very distinct heads, and consist, first, of limestones or carbonates of lime, with more or less admixture of foreign substances; secondly, of magnesian limestones, or carbonates of lime and magnesia; thirdly, of sandstones; and fourthly, of granites, porphyries, and other igneous rocks, but these latter, when sufficiently hard and compact to resist decomposition, are usually too hard to be used economically in great public works, and they will not therefore require any lengthened description.

#### I. LIMESTONES.

Of limestones there are two or three very distinct kinds, each of which is worthy of notice with respect to its Geological position, as well as its economic value. The first of these includes the argillaceous limestones common in

Silurian rocks, and found also in Devonshire and Cornwall in rocks of the Devonian period, but stone of this kind is not confined to any particular Geological localities, being met with also in some beds of the Cretaceous series.

The second, and a much more important group of limestones for building purposes, comprises those (chiefly of the mountain limestone series) which are crystalline and compact, and often of a blue colour. The third series includes the Oolites, (which are the stones most commonly used and the most convenient for ordinary purposes,) abounding in the middle Secondary group of formations, and employed in most of the public buildings that have been erected in the middle, west, and south, of England. These stones, however, vary greatly in relative value as building materials.

The argillaceous limestones of the older rocks are so rarely of sufficient durability to be used for public buildings, that there is no quarry of this kind reported on by the Commissioners. They have indeed mentioned only one argillaceous limestone as of tolerable excellence, and this is an accidental variety of the lower chalk quarried at Totternhoe, near Dunstable, and formerly used in some kinds of external work, but now superseded by Bath stone. Like other kinds of *clunch* (as the lower chalk is sometimes called), this bed forms an easily-cut, and a very useful material for certain kinds of internal decorative work, and has often been used for such purposes in the interior of our cathedrals.

The crystalline carbonates of lime that have been used for building are not very numerous, although they possess many advantages, among which great durability and resistance to decomposition, may be ranked as the principal. Many of them, however, are too expensive to be generally

employed, such as marble and ornamental stones, and the number of fossil remains found in those of Derbyshire and Devonshire sometimes tends to diminish their value by exposing them to unequal decomposition in the parts where the fossils chiefly abound.

It is chiefly the Oolitic limestones that have been employed in England for building purposes; they are so called from the egg-shaped particles of which they are more or less composed, and these egg-shaped particles being cemented together by a calcareous matter of varied character will, of necessity, suffer unequal decomposition unless the oviform bodies and the cement be equally coherent, and of similar chemical composition.

Of the same Geological period, and associated with the Oolitic limestones, there are also some which are called "Shelly," and these, being chiefly made up of either broken or perfect fossil shells cemented by calcareous matter, also suffer decomposition in an unequal manner, because the shells, being for the most part crystalline, offer the greatest amount of resistance to the decomposing effects of the atmosphere. The shelly limestones have a coarse, laminated structure, which is usually parallel to the planes of their beds, and when made use of they require to be placed in a building so that the planes of lamination shall be horizontal.

The Oolitic limestones best known and most extensively used in England, are the following, viz.:—the Portland, the Bath, the Ketton, and the Barnack. Besides these the Caen stone has been a good deal employed in some English buildings of an early date (among the rest in Canterbury Cathedral) and is a stone of great beauty and durability.

THE PORTLAND STONE is obtained from a number of quarries in the Isle of Portland. In a former Chapter,

under the head of 'Descriptive Geology,' I have mentioned the position of this limestone at the top of the Oolitic group of formations, where it appears as a limestone of marine origin, immediately overlaid by freshwater limestones and a bed of vegetable mould, belonging to the Purbeck series.\* This latter bed (called the dirt-bed) is full of fossil roots, trunks and branches of trees often lying in the position of their former growth. Beneath the dirt-bed, the first bed of stone is called the *top-cap*, and is a white, hard, and closely compacted limestone, from three to six or seven feet thick; and to this succeeds the *skull-cap*, which is also well compacted, but is irregular in its texture, and contains numerous cherty nodules.

The skull-cap is not more than half the thickness of the overlying bed, and is succeeded by what are called the *roach* beds, which are incorporated with the freestone beds below, but are full of cavities, (originally occupied by shells and still occasionally containing casts of them,) and near the upper part are occasional bands of oyster shells and irregular layers of flint. The whole series down to the roach forms the capping of the regular freestone, and the first bed below it, called 'the top-bed,' is the best stone of the quarries. It is fine-grained, and free from shells and hard veins; it varies considerably in thickness, being sometimes not more than three, but frequently eight feet thick, and it occasionally alternates with roach beds, or, in other words, with beds that have once been fossiliferous, but are now porous and irregular. Below the top bed, in some of the quarries, is a middle, or *curf* bed, and then a third or bottom bed, similar in appearance to the top bed, and of the same component parts, but the stone is ill-cemented, and will not stand the weather.

\* See section, vol. i. p. 422.

The description above given applies to the stone in its ordinary condition, and when of good quality ; but in most of the quarries, and sometimes in different parts of the same quarry, it varies very considerably. Generally speaking, the stone is inferior, and will not stand the weather, when it contains flints, or when it immediately underlies layers of flints ; while the most durable stone has its cementing matter in a solid and half-crystalline state, and in the least durable kinds this part is earthy and powdery. The shelly parts are considered, on the whole, inferior, but are occasionally worked.

The Portland stone is well known to be of a whitish-brown colour: its average specific gravity, when dry, is about 2·145, (rather heavier than the ordinary qualities of building limestones,) and it absorbs about one-ninth of its bulk of water. The weight of particles disintegrated after eight days' exposure of 2-inch sided cubes to Brard's process,\* was found to be 2·7 grains, and its cohesive

\* The object of this process is to discover in a short time the relative resistance offered by different kinds of stone to the action of damp and frost, and therefore to determine the durability of stones, with reference to exposure. Its accuracy was determined by a number of experiments made in different parts of France and Switzerland, and by different persons, and reports to this effect were published in the *Annales de Chimie* for 1828, vol. xxxviii.

The following is an abstract of the method recommended to be employed.

1. Several specimens should be selected from the questionable parts of a block of stone to be tried, taking, for instance, those which present differences of colour, grain, or general appearance.

2. These fragments should be cut into two-inch cubes, with sharp edges, and each must be marked carefully, so that the part of the block from which they came may be referred to.

3. There must next be prepared a saturated solution of Glauber's salts (sulphate of soda), the solution being made with cold water, and a quantity of the salt left for an hour or two at the bottom, after as much has been taken up as the water will at first absorb. (It will be found that a quart of water absorbs more than a pound of this salt at ordinary temperatures.) The saturated solution is then to be boiled, and the cubes prepared are to be plunged into the vessel in which the solution is boiling violently, care being taken that each one of the cubes is completely submerged. The boiling is then to be kept up, and the stones re-

power is moderate. It is composed of upwards of 95 per cent. of carbonate of lime, with a little more than 1 per cent. both of silica and carbonate of magnesia.

Portland stone has been much used in the metropolis; St. Paul's Cathedral and several churches, the Goldsmith's Hall, the Reform Club House, and many other public edifices being built of it. It can be obtained in blocks of almost any required size, and is readily conveyed by water to London. It is, however, not a cheap stone, either as delivered rough, or in working, exceeding in this respect most of the common limestones, and some of the magnesian limestones. On the spot, and when exposed only to the open air in the country, it appears to be an exceedingly durable stone; an old church in the neighbourhood of the quarries, built in the fourteenth or fifteenth century,

tained in the boiling liquid for half an hour exactly. If a longer period elapses, the effects produced exceed those of ordinary atmospheric action and frost.

4. When the boiling is completed, each specimen is to be withdrawn successively, and suspended from a string, taking care that it touches nothing else, and is completely isolated. Beneath each there is also to be placed a vessel full of a quantity of the solution in which it has been boiled, care being taken that it contains no fragments of the stone detached during the boiling.

5. If the weather is not too wet or too cold, it will be found that the surface of the stones four-and-twenty hours after they have been suspended are covered with small, white, acicular crystals of salt. When these appear, the cubes are to be plunged into the vessel below them, to get rid of the efflorescences; and this is to be done repeatedly, as often as crystals of salt are thrown out during the experiment.

6. If the stone resists the decomposing action of damp and frost, the salt does not force out any portions of the stone with it, and one finds neither grains, nor laminae, nor other fragments of the stone in the vessel. If, on the other hand, the stone yields to this action, small fragments will be perceived to separate themselves, detached even from the first appearance of the salt, and the cube will soon lose its angles and sharp edges. The portions thus detached are preserved at the bottom of the vessel over which the cube is suspended, and their weight may be determined at the completion of the experiment.

7. The period of duration of the experiment, as recommended by M. Brard, should be four days, and at the end of that time the particles detached should be carefully weighed. The result is an index of the amount of disintegration suffered by the stone, and may be compared with similar results from other stones.



being in very good condition, and retaining the original chisel marks on its north front. This is the case, also, with the remains of the keep of Bow and Arrow Castle, also in Portland Island, and many centuries old. The ashlar resembles the top bed, and is in perfect condition; and other parts, which appear to be of the cap-bed, are also in good condition.\*

“As an instance, however, of the difference in the degree of durability in the same material, when subjected to the effects of the atmosphere in town and country, may be noticed the frustra of columnus, and other blocks of stone, that were quarried at the time of the erection of St. Paul's Cathedral in London, and which are now lying in the Island of Portland, near the quarries from whence they were obtained. These blocks are invariably found to be covered with lichens, and although they have been exposed to all the vicissitudes of a marine atmosphere for more than one hundred and fifty years, they still exhibit beneath the lichens their original form, even to the marks of the chisel employed upon them; whilst the stone which was taken from the same quarries, (selected, no doubt, with equal, if not greater care, than the blocks alluded to,) and placed in the Cathedral itself, is, in those parts which are exposed to the south and south-west winds, found in some instances to be fast mouldering away.”†

THE BATH STONE, which, like the Portland, is one of those most commonly used and most admired for public buildings in England, is obtained from three principal localities, two of them in Wiltshire, and one in Somersetshire.

\* The new church in the island of Portland, built in 1766, of the variety of Portland stone called Roach, is in an excellent state throughout, even to the preservation of the marks of the chisel.

† Report, &c. p. 5.

Its Geological position is in the lower part of the Oolitic series. It is more perfectly oolitic in its structure than the Portland stone, and has a rich cream colour. It is moderately fine-grained, is composed of about  $94\frac{1}{2}$  per cent. of carbonate of lime, and  $2\frac{1}{2}$  per cent. of carbonate of magnesia, but no silica: its specific gravity is 1.839, nearly one-seventh less than that of Portland stone,—its cohesive power is only 21, and the number of grains lost by disintegration by Brard's process is as much as ten. It absorbs nearly one-third of its bulk of water.

Some of the most ancient quarries of the Bath stone are on the escarpment of the Oolite at Box Hill: there is here a total thickness of forty-five feet of workable stone, consisting of from 12 to 15 feet of *scallet*, which is the finest grained, and is cut for ashlar: 15 to 20 feet of *corn-grit*, used for dressings; and from 16 to 22 feet of *ground-stone*.

Nearer Bath, at Coombe Down, are several quarries worked in three beds, whose total thickness is about seven feet, and the stone is there applied, amongst other uses, in the manufacture of troughs. Other quarries are worked, also, near Bath, in which there is about 20 feet of workable stone, some beds of which are much employed in coarse sculpture. These latter quarries are all subterranean.

The Bath Oolite is a stone of great beauty; it works very freely in the quarry, (some of the beds cutting almost as readily as chalk,) and hardens on exposure to the air,—it is exceedingly cheap, both as delivered rough and in the after working, and may be obtained of almost any ordinary dimensions, but it certainly cannot be recommended as a durable stone.

The Abbey church of Bath, built of stone from the neighbouring quarries, is partly in fair condition, but the body of the church, in the upper part of the south and

west sides, is much decomposed. Its date is 1576. Where it has been defended by buildings formerly in contact with it, the stone in this building is in a better state, but the reliefs and other ornaments are nearly effaced. Other buildings, not much more than a century old, are also in fair condition, but exhibit marks of decomposition on the west and southern aspects.\*

In the Inferior Oolites at Doultong, in Wiltshire, a bed of shelly limestone has been long quarried, and appears to possess many excellent qualities. It is a carbonate of lime, with a few oolitic grains, and an abundance of small shells, commonly in fragments, and often crystalline: its colour is light brown, its specific gravity considerably greater than that of either of the quarries of Bath stone, and it occurs in four or five beds, whose total thickness is about ten feet, but there are ancient quarries in the neighbourhood where a greater depth of stone is found.

Most of the public buildings in Wells and Glastonbury and the neighbourhood, are of this stone, and the extensive Norman ruins of Glastonbury Abbey, some of them of the eleventh century, are in good condition, the zigzag and other Norman enrichments being perfect. The cathedral of Wells, chiefly of the thirteenth and fourteenth centuries, is also built of similar stone, and although partially decomposed, is in good condition, especially on the south side, and in the central tower. The Chapter House, built in the thirteenth century is in good condition, except the west front, which is decomposed.

THE KETTON STONE and the BARNACK RAG are both of them admirable building-stones, obtained from the lower

\* Henry the Seventh's chapel, in Westminster Abbey, restored about twenty-five years since with Coombe Down Bath stone, is already in a state of decomposition.

Oolitic strata of Rutlandshire and Northamptonshire. The Ketton is a very even grained stone, (the oolitic grains being of moderate size,) and of a dark cream colour, rather streaky when first exposed, but weathering evenly and paler. It contains rather more than 92 per cent. of carbonate of lime and upwards of 4 per cent. of carbonate of magnesia. Its specific gravity is 2·045, and its loss by disintegration 3·3 grains. It absorbs about one fourth part of its bulk of water, and its cohesive power is much greater than that of any other Oolite. It consists of two beds,—the hard upper bed, called ‘Ketton rag,’ being about three feet six inches thick, and the principal mass containing about four feet of Oolite in one or two beds. It is an expensive stone, but worked more easily than Portland.

This stone has been much used in the middle of England, and in the metropolis; many of the buildings in Cambridge are constructed of it, all of which are in excellent condition; and it has been greatly employed in the modern buildings both in Ely and Peterborough Cathedrals.

The Barnack stone belongs rather to the shelly limestones than to the true Oolites, but it is obtained from beds of the same Geological age as the Ketton stone. The colour of Barnack rag is a light whitish brown; it consists of 93·4 per cent. of carbonate of lime, and 3·8 per cent. of carbonate of magnesia; it is partly oolitic, but compact and coarsely laminated with shells and fragments of shells. It is a very little heavier than Ketton stone (S. G. 2·090) but its rate of disintegration by Brard’s process is five times as great, and its cohesive power not more than two thirds. It is, however, a most excellent stone, several buildings of the twelfth and thirteenth century built of it being in admirable condition, and scarcely at all decomposed. It is the material that has been used

in the greater proportion of the churches in Lincolnshire and Cambridgeshire, and it has the advantage of being tolerably cheap.

There are besides these many other limestones in different parts of the country, and of the Oolitic class, which have been locally used, and have been found to possess advantages, greater or less, according to circumstances. Amongst these, I ought perhaps to mention the Oolite of Ancaster, in Lincolnshire, which has been much employed in that county, and of which the lofty tower and spire of Grantham Church (built in the thirteenth century) is an excellent example.

The remarkable siliceous limestone of Chilmark, in Wiltshire, is also worthy of notice for its extremely great cohesive power (nearly three times as great as that of any of the carbonates of lime without silica) and its considerable specific gravity (2.481), in which latter respect it is only inferior to the nearly pure siliceous rock of Darley Dale, in Derbyshire. It contains nearly 80 per cent. of carbonate of lime, more than 10 per cent. of silica, and  $3\frac{1}{2}$  per cent. of carbonate of magnesia. Salisbury Cathedral is built of this stone, and is in excellent condition, except the west front, which is in parts slightly decomposed.

It must not be forgotten while considering the relative disintegration of these different limestones, that those which have a coarse laminated structure, such as the shelly beds, may be exceedingly durable if (as should always be done) care is taken to place them in the building parallel to the planes of the beds. The decomposition, which is exceedingly rapid when the planes of the laminae are exposed, can scarcely even commence at the edges.

## CHAPTER XIII.

APPLICATION OF GEOLOGY TO ARCHITECTURE, *continued*. —  
 MAGNESIAN LIMESTONE. — SANDSTONES. — CAUSES OF DECOM-  
 POSITION OF DIFFERENT BUILDING STONES. — UNSTRATIFIED  
 ROCKS.

## II.—THE MAGNESIAN LIMESTONES.

THE magnesian limestones vary in quality even more than the carbonates of lime, and require, therefore, to be selected with still greater care and consideration when they are to be employed for building purposes. They are strictly confined in their distribution in England to the newer beds of the Palæozoic period, and they overlie the lower beds of the lower New red sandstone, being separated by those strata from the coal measures. They are rarely quarried except in the counties of Derbyshire and Yorkshire.

The magnesian limestones have not hitherto been much used at a distance from the quarries, and their excellent qualities as building stones hardly seem to have been generally recognised till it was determined to recommend one of them for the new Houses of Parliament. They are chiefly obtained from four principal localities, and it will be most convenient to consider these in their geographical order, beginning with Bolsover, in Derbyshire, the southernmost, and proceeding northwards to the

others, which are respectively in the vicinity of Bawtry, Doncaster, and Tadcaster, in Yorkshire.

The Bolsover quarries (from which the stone for the new Houses of Parliament is procured), and several others that have recently been opened in the neighbourhood, contain about twelve feet of workable stone, in numerous bands from eight inches to two feet thick. This stone is of a light yellowish brown colour, which does not appear to change by exposure. It has a pearly lustre when broken, and a peculiarly beautiful semi-crystalline structure. Its chemical composition consists of 51 per cent. of carbonate of lime, 40 per cent. of carbonate of magnesia, and more than  $3\frac{1}{2}$  per cent. of silica. Its specific gravity is 2.316, or considerably greater than that of any other limestone, and its cohesive power is nearly four times as great as that of Portland stone, and very much greater than that of any other limestone or sandstone examined by the Commissioners. Its disintegration also was found to be exceedingly small.

This admirable stone is not expensive, being cheaper than Portland stone, and worked as easily, but it does not seem to have been much used at a distance from Bolsover, except in slabs for paving. Its qualities of durability are well tested in Southwell Church, Nottinghamshire, a building of the tenth century, and in admirable condition.

In this church the Norman portions, built of stone similar to that of Bolsover Moor, are throughout in a perfect state, and the mouldings and carved enrichments are as sharp as when first executed.

The Roche Abbey quarries near Bawtry, in Yorkshire, exhibit another instance of semi-crystalline magnesian limestone, but the quality is not at all equal to the stone of Bolsover Moor, and, although thick, the stone is so irregu-

larly bedded as to give no certainty as to large blocks. This stone contains only  $39\frac{1}{2}$  per cent. of carbonate of magnesia and  $57\frac{1}{2}$  of carbonate of lime, and it is both the lightest and the least cohesive of all the magnesian limestones.

It would appear that "the nearer the magnesian limestones approach to equivalent proportions of carbonate of lime and carbonate of magnesia, the more crystalline and the better they are in every respect."\* In spite of the imperfections of the stone however in this respect, Roche Abbey, built of it in the thirteenth century, is said to exhibit generally a fair state of preservation; but this is accounted for by its semi-crystalline condition and the resistance which the stone therefore offers to the decomposing action of the atmosphere. But some portions of the building have, notwithstanding, yielded to the effects of the atmosphere and exhibit marks of decomposition.

There are two considerable magnesian limestone quarries in the neighbourhood of Doncaster, from both of which building stone has been obtained, though they appear to differ very considerably in value. The Brodsworth quarries produce a friable stone, with a tendency to oolitic structure; the thickness of the beds is considerable, the price low, and blocks of great size can be procured; but it has not stood the test of time. The old church of Doncaster, built in the fifteenth century of this stone, is so much decomposed, that it is now undergoing general and extensive repair.

The Park-nook quarries yield a much better stone than those of Brodsworth, and contain about fifteen feet of workable material, which may be obtained of any practicable size. There are buildings of this stone about a century old in perfect condition; and it is considered

\* Report, &c. p. 7.



by the Commissioners worthy of being recommended as a desirable building material. It is of a cream colour, and partly crystalline.

The Huddlestone quarries, and others in the neighbourhood of Sherburne, supply also a good semi-crystalline magnesian limestone of a whitish cream colour, which has been very much and very long used for building purposes, and of which, indeed, 'Westminster Hall' is built. Jackdaw Craig, near Tadcaster, and Smawse, in the same neighbourhood, are also well known for their quarries, which have supplied the stone for public buildings in many parts of Yorkshire.

The stone from Jackdaw Craig was employed in the building of York Minster, the transepts of which date from the thirteenth, and the tower, nave, &c. from the fourteenth century; but, from the generally decomposed state of all this stone, more especially in the mouldings and enrichments, it is evidently not one that should be selected for durability. It is of a dark cream colour, not very crystalline, and it lies in irregular beds, varying from a few inches to three feet in thickness. The upper beds, which are the worst, have been the most quarried, and many of the churches of York, besides the Cathedral, are proofs of the want of judgment in the architect who selected a material so readily injured by exposure.

The Smawse quarries on Bramham Moor, contain a stone slightly crystalline, and probably for that reason more durable than the former. It is not, however, very greatly to be depended on, as in Beverley Minster, (twelfth, thirteenth, and fourteenth centuries) the west tower, central tower, and other parts built of this stone are in good condition, while in other parts of the building the same material is decomposed. The ancient parts

of St. Mary's Church at Beverley, supposed to have been partly built of the Bramham Moor stone, are also in a very crumbling state, even to the total obliteration of many of the mouldings and enrichments.

The Huddlestone stone, however, which is much more perfectly crystalline, is also a more uniformly excellent building material. Huddleston Hall, built in the sixteenth century of this stone, is in excellent condition, exhibiting in perfect preservation the mouldings of a window in the south-west front; and a church at Hemmingborough, of the fifteenth century, and constructed of a material resembling the stone from Huddlestone, does not exhibit any appearance of decay.

### III.—SANDSTONE.

The number of the different kinds of sandstones that have been used for building purposes is so great, and their qualities vary so indefinitely, that it is no easy matter to place them before the reader in such order that he shall perceive the general conclusions that may be derived from the investigation. I will endeavour, however, to bring them together into groups, and exhibit in this way the result rather than any detailed account of particular beds.

Sandstones have been selected for building purposes from the whole series of formations, including the oldest Palæozoic and the most modern Tertiary rocks, but it is chiefly those obtained from the older rocks that have been worked on a large scale, and to a great extent. This is so much the case, indeed, that of the whole number of quarries of sandstone (amounting to sixty-three) visited and reported on by the Commissioners, as many as fifty

were from the Palæozoic rocks, thirty-seven of them being from the Carboniferous system, and the remaining thirteen from the Old red sandstone. Perhaps the most convenient method of considering these different stones will be to group them according to their Geological position.

Of the sandstones of the Middle Palæozoic period there are two very striking varieties; the first obtained from the beds of the Old red sandstone, running up through the counties of Stirling, Perthshire, and Forfarshire in North Britain, and from a fragment of the same bed on the coast of Rosshire; and the second, from the very different beds of the same age in Monmouthshire.

The former stone, chiefly shipped from Dundee, is of moderately fine grain, of a purplish grey colour, micaceous in the plane of stratification, and composed of siliceous grains, united by a calcareo-argillaceous cement, which is sometimes also siliceous. The stone lies in beds of from three to six feet thick, and exhibits a total thickness of fifty or sixty feet. It is very heavy and close-grained, and has been long and extensively used in the neighbourhood in which it is found, but is rather expensive to work. The Stirlingshire beds differ from the Forfarshire in their colour, which is a whitish grey, in the absence of calcareous matter in the cement, and also in the thickness of the beds, which is considerably less. The Perthshire beds resemble the Stirlingshire rather than the Forfarshire varieties, but the cementing material, although principally siliceous, is mixed with oxide of iron, instead of with argillaceous matter. All these stones are good and durable.

The Old red sandstone of Monmouthshire is quarried near Chepstow, and was employed in the erection of

Tintern Abbey. The bed is of a light greyish brown colour, of an irregular grain, cemented by an argillo-siliceous cement, and containing ferruginous spots, and occasional plates of mica. It is in beds, the thickest of which varies from ten to twelve feet. Tintern Abbey is in unequal condition, but the stone is for the most part perfect; it is covered with lichens.

The sandstones of the Carboniferous system belong chiefly to the uppermost beds of the group, and there are few places where some tolerably good building-stone may not be obtained if these upper beds predominate.

The carboniferous sandstones of Craigleith and other quarries in the neighbourhood of Edinburgh, and the county of Linlithgow, in Scotland, have been much used, and are some of them of excellent quality. They are generally of a lightish grey colour, fine grained with a siliceous cement, slightly calcareous, and containing a little mica in the planes of bedding. The Craigleith stone consists of  $98\frac{1}{4}$  per cent. of silica, and little more than one per cent. of carbonate of lime; it is not a very heavy stone, and its cohesive power is second only to the magnesian limestone of Bolsover. It has been used extensively of late years in public buildings at Edinburgh, and also for landings, steps, and pavings in London, and has stood exceedingly well. The beds of it vary much in thickness, the thickest being ten feet; but there are about 200 beds in all, and the whole depth of rock quarried is as much as 250 feet. It is rather an expensive stone, and more difficult to work than Portland stone. The quarries at Uphall, in Linlithgowshire, also supply a good material, much used in some of the modern buildings in Edinburgh. It is not so heavy, nor is its cohesive power so great, as the Craigleith stone.

The coal grits used for building purposes, and which are obtained from the neighbourhood of Glasgow, are not so uniformly good as those near Edinburgh. The 'Giffneuch' quarries contain about twenty-two feet of good rock, and twenty feet of inferior, but in the 'President' quarries, where the stone is exceedingly thick, it is porous, uneven in tint, and although at first of a pale brownish grey, soon assumes a foxy colour. The sandstones in both are fine grained; in the former (the Giffneuch) the grains are cemented by a calcareo-siliceous, and in the latter by an argillo-siliceous matter, and both of them are micaceous.

Of the ancient buildings of Glasgow, the High Church, built in the twelfth century, of sandstone from the neighbourhood, is very much decomposed, particularly on the south side, and the old quadrangle of the college (of the time of James II.) is also decomposed. Of the modern buildings, the Hunterian museum (1804) said to be of stone from the President quarry, exhibits traces of decomposition, but it is built of different stones, some of which are much changed, and some almost perfect. Several buildings erected of stone from the Giffneuch and other quarries in the neighbourhood, are quite perfect.

The coal grits of the Newcastle coal-field have been the chief building-stones used in Newcastle, Durham, and the other towns of the district. In the neighbourhood of Newcastle several quarries are worked, amongst which are the Heddon and Kenton; both of these contain stone of a palish brown, or grey colour; the quartz grains are united by an argillo-siliceous cement with iron, and the beds are of variable thickness and quality. It would appear from the condition of the buildings that have been erected of these stones, that they are extremely liable

to decomposition, and this is not to be wondered at, since their cohesive power is small, their rate of disintegration, measured by Brard's process, very rapid, and they absorb nearly one-fourth part of their bulk of water. They are very bad specimens of the group of stones to which they belong.

Although, however, the coal-grits of Newcastle are so indifferent, some of the carboniferous rocks found in the county of Durham, a little further to the south, offer better examples of building materials, while others again, such as those of which Durham Cathedral is built, are quite as decomposable as the Newcastle stones. The colour of most of the sandstone quarried in the neighbourhood of Durham is a pale whitish brown, with ferruginous stains, and the quartz grains are cemented with an argillaceous cement, partly derived from decomposed felspar. Plates of mica are also found distributed through the stone.

The Stenton quarries, near Barnard Castle, supply an excellent material, and of this the circular keep of Barnard Castle (of the fourteenth century) is built. It appears to be in perfect condition.\* It would seem from these differences that in this part of the North of England the sandstones of the millstone-grit are better adapted for building purposes than those of the coal measures, for the only good quarries recorded are in the former series, and the worst are all in the latter.

The millstone-grit quarried at Gatherly Moor, near Richmond, in Yorkshire, is of a cream colour, and made up, like the Stenton beds, of moderate-sized quartz grains,

\* Eccleston Abbey, Yorkshire, (of the thirteenth century,) is built of stone similar to that of the Stenton quarry, and the mouldings, and other decorations, such as even the dog's-tooth enrichments, are in perfect condition.

united by an argillo-siliceous cement. The keep of Richmond Castle (of the eleventh century) built of sandstone of this kind, is in good condition, and the mouldings and carvings in the columns of the windows are in a perfect state.

There have been a number of quarries opened in the neighbourhood of Leeds, all of them in the coal measures, and these supply a coarsish-grained sandstone with argillo-siliceous cement, having plates of mica in the planes of the beds. It is not likely that they will prove of very durable quality, but there is no account of their having hitherto shewn symptoms of decay in the various public buildings of the town.

In various parts of Yorkshire and in Derbyshire, wherever the sandstones of the coal measures and the millstone-grit have been used for building purposes, they are found to exhibit nearly the same general character and local differences as those already described in other parts of England further to the north. The coal-grits are usually decomposable, and, perhaps, as a general rule, more so than the millstone-grits.

A whitish or reddish-brown stone, belonging to the Lower New red sandstone formation, and consisting of fine siliceous grains, with magnesio-calcareous cement, is quarried at Mansfield, in Nottinghamshire, and appears to form a tolerable building-stone, shewing no signs of decomposition in those buildings that have been hitherto erected of it.

The New red sandstone near Stafford, and in some other places, has been occasionally quarried for building purposes, but it is rarely sufficiently indurated to serve even for those of the commonest kind.

The Lias, like the New red sandstone, although for a very

different reason, rarely offers any valuable building material, and in most cases is totally inapplicable even for the commonest purposes. It has, however, been sometimes used, as for instance, in portions of Glastonbury Abbey, where several lias columns and capitals are to be found, but they are nearly mouldered away although from those parts which remain the material employed seems to have been of the most compact kind.

Returning, however, to the sandstones, we again find them overlying the lias and occupying the lower part of the Oolitic group of formations, as exhibited in the north of England, on the Yorkshire coast, where several sandstone beds have been much worked near Whitby, supplying an admirable building-stone, shipped to many parts of England. This stone is of a colour varying from pale to rather dark brown, but it has sometimes a warm tint. It is extremely light, its specific gravity being less than that of almost any other sandstone. It occurs in beds of considerable thickness, and can be obtained of almost any required size, and it is inexpensive and works freely.

Of ancient buildings of this stone, Whitby Abbey, of the thirteenth century, may be cited, and it is generally in good condition, with the exception of the west front. The stone used in the Abbey is of two colours, brown and white, and the former is in all cases more decomposed than the latter, a fact which is doubtless owing to the presence of a larger per centage of iron. A very large number of modern buildings, not only in the neighbourhood of Whitby, but in London, Cambridge, and even so far distant as Exeter, are constructed of material obtained from the Whitby quarries, and they are all of them at present in excellent condition.



With regard to the sandstones of formations more modern than the Oolites, but few of them are used in England for building purposes, except very locally. Among those, however, most worthy of notice, is a stone obtained from the Hastings Sand, at Calverly, Tunbridge Wells, which has been much employed of late years in the neighbourhood, and which, from its cheapness, variegated colour, and the facility of procuring large blocks, offers many advantages. It yet remains to be seen how far it can be considered a durable stone.

The upper beds of the greensand are quarried at Gatton, near Merstham, in Surrey, and supply a fine-grained stone, with a calcareo-siliceous cement, of a greenish light-brown colour, sometimes used for building purposes. It is, however, liable to decomposition, and, except when very carefully selected, and placed in the building with reference to its position in the bed, it offers little resistance to the action of the weather.

The beds of the Tertiary period in England, being chiefly composed of clays and loose sands, can only be used for building purposes when converted into brick. The only exceptions to this condition consist of a fresh-water limestone worked at Binstead, near Ryde, in the Isle of Wight, and some unimportant argillaceous sandstones at Bognor and elsewhere.

I have now completed my account of those kinds of stone that are most likely to be selected for public buildings, and which are obtained in our own country; and several observations suggest themselves with regard to the different qualities of these stones, and their relative durability under certain circumstances of exposure; while a general resemblance may be traced in the qualities of stones deposited under similar Geological conditions.

With respect to the decomposition of stones employed for building purposes, it is greatly influenced, as well by the chemical and mechanical composition of the stone itself and by the nature of the aggregation of its component parts, as by the circumstances of exposure. The Oolitic limestones will thus suffer unequal decomposition, unless the little egg shaped particles, and the cement with which they are united, be equally coherent, and of the same chemical composition. The shelly limestones, or 'rags,' being chiefly formed of fragments of shells, which are usually crystalline and cemented by a calcareous paste, are also unequal in their rate of decomposition, because the crystalline parts offer the greatest resistance to the decomposing effects of the atmosphere. These shelly limestones have also, generally, a coarse laminated structure, parallel to the plane of stratification, and, like sandstones formed in the same way, they decompose rapidly when used as flags, where their plane surfaces are exposed; but if their edges only are laid bare, they will last for a very long and almost indefinite period.

Sandstones, from the mode of their formation, are very frequently laminated, and more especially when micaceous; the plates of mica being generally deposited in planes parallel to the beds. Hence, as I have just observed, if such sandstone, or shelly laminated limestone, be placed in buildings with the planes of lamination in a vertical position, it will decompose in flakes, more or less rapidly, according to the thickness of the laminae; whereas, if placed so that the planes of lamination are horizontal,—that is, as in its natural bed, the edges only being exposed, the amount of decomposition will be comparatively immaterial. The sandstones being composed of quartzose or siliceous grains, comparatively indestructible, they are

more or less durable according to the nature of the cementing substance ; while, on the other hand, the limestones and magnesian limestones are durable in proportion rather to the extent in which they are crystalline ; those which partake least of the crystalline character, suffering most from exposure to atmospheric influences.

“ The chemical action of the atmosphere produces a change in the entire matter of the limestones, and in the cementing substance of the sandstones, according to the amount of surface exposed. The mechanical action due to atmospheric causes, occasions either a removal or a disruption of the exposed particles ; the former by means of powerful winds and driving rains, and the latter by the congelation of water forced into, or absorbed by, the external portions of the stone. These effects are reciprocal, chemical action rendering the stone liable to be more easily affected by mechanical action, which latter, by constantly presenting new surfaces, accelerates the disintegrating effects of the former.”

On the whole, it would appear that, where there are no local reasons to the contrary, preference should be given to limestones over sandstones for most public buildings intended to be handed down to future ages ; and this on account of their more general uniformity of tint, their comparatively homogeneous structure, and the facility and economy of their conversion to building purposes. Amongst the limestones, also, those which are most crystalline are to be preferred ; and some of the magnesian limestones seem to offer the greatest advantages of durability, uniformity of structure, beauty of appearance, and facility of conversion ; but it should be clearly understood, that many other limestones, and many sandstones, also form admirable building stones, and these are so distributed through

the country, that there is now no excuse for those architects and engineers who neglect to examine carefully into the relative durability and excellence of the stone employed in any edifice about to be constructed.

It might also easily be shewn, that if more attention had been paid to these various qualities of the stone made use of in buildings, the frequent decay or decomposition, observable in many of those which have been erected even within a few years, might have been avoided, at comparatively small cost, and we should find fewer of our public edifices losing all traces of the finer work of their original structure. So long, however, as the opinion and judgment of the mason is allowed to decide on the stone to be used, so long will this unpardonable result take place, for "the mason almost always judges by the freedom with which a stone works,—no doubt an important element in the cost of a building, but certainly one which should not be permitted to weigh heavier in the scale than durability,—and hence many a fine public or large private building is doomed to decay even, in some cases, within a few years." \*

Although the unstratified rocks are not very often employed in the construction of public edifices, because, when not decomposable, they are usually of extreme hardness, they still require to be considered among building materials, and are occasionally selected for bridges, public monuments, &c., and sometimes for ornamental work. The principal material of this kind used in England consists of granite chiefly obtained from Cornwall and Aberdeen, both of which places offer considerable abundance of excellent stone, varying in colour, texture, and durability. The Cornish granite has been exported chiefly

\* De la Beche's Report, &c., *ante cit.* p. 486.

from Penryn, at the rate of upwards of twenty thousand tons yearly. The Aberdeen granite is also very extensively worked, and resists exposure apparently almost as well as the ancient Syenite of Egypt. Both are more frequently used for road-making than as building materials, although their great beauty and the high polish of which they are capable renders them admirably adapted for the latter purpose, especially for internal decorative work.

The Isle of Jersey also supplies an excellent granite of a beautiful flesh-colour, and tolerably durable. The Granites, or rather Syenites of the Malvern Hills and Charnwood Forest, in Leicestershire, are only used locally.



ST. HELEN'S BAY, ISLE OF JERSEY.

## CHAPTER XIV.

## THE APPLICATION OF GEOLOGY TO AGRICULTURE.—THE FORMATION OF SOILS, AND THE MIXTURE OF SOILS.

CONSIDERING the applications of Geology to practical subjects as comprised under the three great subdivisions of Mining, Architecture, and Agriculture, and having already spoken of those operations which are carried on beneath the earth's surface, and which belong to the art of Mining ; and those in which the surface of the globe is made use of as a basis on which the works of Engineering and Architecture depend ; so now, in the third place, I have to direct the reader's attention to the materials which compose the outer coating of vegetable soil upon the earth, and the dependence of these on its geological structure, and on the actual physical condition of the strata, and groups of strata, already described. It is this subject to which the name of "Agricultural Geology" more particularly belongs ; but this title includes, also, a number of incidental matters, upon a proper understanding of which the right cultivation of the land depends.

Viewing the subject of Agricultural Geology in all its bearings, it may I think be properly and conveniently considered under three heads, each one of which in turn will be found well worthy of careful attention. Under the first of these heads we may discuss the actual nature of vegetable soil in different geological districts, and the circumstances under which it has been derived from the sub-

jacent or other rocks. The second head has reference to the physical as well as geological structure of the earth's surface, and to the nature of the underlying strata, and involves the consideration of drainage; while under the third must be discussed the geological conditions involved in the supply of water to the surface by means of springs and wells, and the artificial methods that may be adopted to discover and render available for the use of man those great subterranean reservoirs of water often existing in the bowels of the earth. In the present chapter I shall confine myself to a description of the modifications that the agriculturist may effect on the natural soil of a district by availing himself of the means of improvement afforded by Nature, and suggested by a knowledge of Geology.

In following out this plan it will be found that most of the interesting facts in Agriculture, to which attention has been so especially paid of late years, will require to be discussed. I shall endeavour, in the first place, to shew the importance of attending to the geological structure of a district by explaining the origin and use of soils, and of the subsoil, and by stating shortly the different conditions that must be fulfilled in order that land may be fertile. I shall then mention the facts hitherto determined with respect to the principal constituent elements of fertile soils, and their relative preponderance and value in each one of the principal groups of strata of which the earth's crust is composed; and I shall conclude by directing attention to the bearing of the subject on the valuation of land, and the benefit of geological knowledge to the land-agent and the surveyor.

The actual mineral substances of which soils are made up are exceedingly few and simple, consisting of a considerable proportion of silica, more or less alumina and carbonate of lime, and a small quantity of magnesia; but these

are associated with a variable, although never very large, proportion of carbon, chiefly furnished by the decay of vegetable and animal matter, without which no vegetation that is useful to man can be supported. It is, indeed, owing to the presence of carbon, (which in the state in which it is found in vegetable soils is called *humus*,) that actual fertility is communicated to the otherwise barren mineral particles of which the soil is chiefly composed; but the main substance of the soil, and those materials by means of which the organic ingredients are rendered available, must in all cases have been derived from the degradation of the subjacent rock, or from the degradation of some other rock, which has been brought there by the action of running water, or by the labour of man.\*

Beneath the soil, with its usual proportion of decayed organic matter, there is also in most cases a layer, of somewhat similar mineral composition, lying below ordinary ploughing, but of great use in promoting the fertility of the land. This is called the subsoil, and it affords a basis into which the roots of trees can penetrate, and whence they obtain an amount of nourishment proportionate to their size. Like the soil itself, it acts chiefly mechanically, and it is of the most vital importance with reference to the drainage of the land. "An impervious clayey subsoil retains the surface water in the soil, and thereby renders it

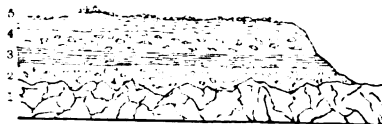
\* The fertility of the soil is generally supposed to depend on the presence of a peculiar substance, to which the name *humus* has been given. Humus, it would appear, is nothing more than woody fibre in a state of decay, and it acts in the same manner in a soil permeable to the air as in the air itself.

The property of woody fibre to convert surrounding oxygen gas into carbonic acid diminishes in proportion as the decay advances; and at last a certain quantity of a brown, coaly-looking substance remains, in which this property is entirely wanting. This substance is called *mould*, and is the produce of the complete decay of woody fibre, and in this state it is an excellent vehicle, conveying freely to the roots of vegetables the nutritive matter on the surface which is carried down by the rain.—Liebig's Organic Chemistry of Agriculture, p. 46.



wet, cold, and unproductive ; while, on the contrary, when the subsoil is too open, the soil is so effectually drained of its moisture that the plants languish for want of the medium by which their food is conveyed to them.”\*

It may readily be shewn that the subsoil is immediately, and the soil intermediately, derived from the decomposition of the subjacent rock, so that in any case the fertility of the land depends on the geological structure of the district. It would, also, be easy to shew that, by taking advantage of the presence of certain mineral substances beneath the surface, a soil naturally barren may often be rendered fertile. The whole subject of mineral manures consists in the proper employment of such substances as may counteract the injurious qualities of a barren or poor soil, and either supply the want of some indispensable element of the plant to be cultivated, or prepare the soil to receive those atmospheric influences which are essential to the development of vegetable life.



FORMATION OF A SOIL BY THE DECOMPOSITION OF THE UNDERLYING ROCKS.  
CLIGGA HEAD, FERRANZABULOE.

- |                    |  |
|--------------------|--|
| 1. Firm granite.   | 3. Thin layers of decomposed granite.    |
| 2. Head of rubble. | 4. Coarse granitic gnt, clay and stones. |
|                    | 5. Black granitic soil.                  |

The above diagram offers a remarkable instance of the formation of a soil by several gradations, proving the existence of a powerful denuding force, which has formerly moved over a large portion of the earth's surface. The whole section includes about nine feet, and indicates a

\* Whitley's Agricultural Geology, p. 75. This work contains a number of admirable practical details, likely to be of great value to the farmer and the land-agent.

series of successive operations, the result of long-continued aqueous action ; but, although such an appearance is not uncommon, it must not be supposed that it is invariable, or that a violent rush of water is necessary for the formation of a soil. Rain penetrating into the crevices of an exposed rock, and succeeded by frost, crumbles down the hardest materials, and, if these crumbled portions are washed away, they are rapidly succeeded by others, so that a soil is formed, which at length, under favourable circumstances, becomes covered by mosses and lichens, and from their decay is obtained that supply of carbon and other materials which in process of time renders the soil fit for the growth of other vegetables which are useful to man.

In either case, however, the result to the agriculturist is the same, for there is a superficial coating of *mould*, and a subsoil chiefly or entirely mineral between the mould and the parent rock.\*

An examination of the soil, and a chemical analysis of it, will in most cases immediately shew that the soil, as well as the subsoil, are derived from the underlying rock ; and it seems that this extends even to the colour, which is white in chalky soils, red on the New red sandstone and the ochraceous beds of the greensand, and yellow on the clays and clay-slate, &c. : but it will not be expected that these conditions should hold when there is a thick bed of superficial detritus, such as gravel ; for the gravel must then be looked upon as the parent rock, and the condition of the soil will be little influenced by the actual underlying bed.

There are one or two general principles with regard to this part of the subject, which it may be worth while here to enunciate, but which it will not be necessary to enlarge upon or illustrate.

\* The amount of organic matter required to give fertility to a soil varies from three to ten per cent.

The *depth* of a soil is chiefly dependent on the nature of the subjacent rock, and on its ready decomposability by atmospheric agents.

The *texture* of a soil also depends on the parent rock as to whether it shall be loose and gritty, or tough and clayey, and varies according to the tendency of the rock to decompose and the manner in which it is affected by decomposition.

The *fertility* of a soil depends partly on its depth and texture, and partly on its possessing those mineral constituents which enter into the structure of the plants to be grown upon it.

The *use* of the soil in enabling plants to grow is twofold: first mechanical, the soil affording the plant a firm foundation, and enabling its roots to take up certain quantities of organic and inorganic substances necessary for its nutriment; and secondly chemical, inasmuch as all plants, without exception, possess a certain amount of inorganic as well as organic constituents, which after undergoing decomposition and entering into new combinations are taken up from the soil, and assimilated for the use of the living vegetable. These substances are required, also, to be present in the soil in such a state that the roots of the plants are able to absorb them.

Liebig states that it is distinctly proved, in analyses made by De Saussure and Berthier, that the nature of a soil exercises a decided influence on the quantity of the different metallic oxides contained in the plants which grow upon it;\* but it does not follow thence that the actual quantity of alkaline bases varies; and it appears, on the contrary, from other investigations, that the total amount of oxygen united to these bases is always the same

\* Organic Chemistry, p. 95.

in the same plant, and therefore that the proper quantity of some of them as bases is essentially necessary; the growth of the plant being arrested when these substances are wanting, and much impeded when they are deficient.

The alkalies are often supplied to the soil by rain-water, where they are certainly present, although it is not known in what form they exist. Besides these mineral substances, and some others, the presence of carbon is absolutely necessary, as I have before mentioned; and the action of the weather, the absorption of rain-water, and, above all, the chemical changes constantly going on in the process of gradual oxidation, (the oxygen being obtained from the atmosphere,) effect the necessary alterations in the different constituents of the soil, and render it fit to support vegetable life.\*

It will now be seen in what way the soil acts, and how far vegetation depends on the actual materials of which it is composed. If any of the constituent parts are wanting, they may usually be supplied at no very great distance, and it is chiefly such soils as do not suffer decomposition that are necessarily and hopelessly barren; but these are so few, that they need hardly be the subject of consideration.

Perhaps one of the most common examples of an ordinary barren soil is that in which the soil is composed of silex, either pure and in the form of compact rock, or is made up of loose grains of sand, mingled only with a cer-

\* Some plants, as the grasses, require a considerable quantity of silex for their proper growth and nourishment; and this, which is chiefly present in the stalk, is supplied in the form of silicate of potash. But the grasses also require phosphate of magnesia, which is an invariable constituent of their seeds; and thus the presence of phosphorus, potash, silica, and magnesia in the soil is absolutely necessary for the proper growth and ripening of a crop of wheat. Other plants possess other salts and alkaline bases, and in different proportions, and all these different substances require to be presented to the roots of the vegetable in the most convenient form for absorption.

tain proportion of alumina and oxide of iron, not sufficient to admit of the ready growth of plants. Such soils as this are to be found on some parts of the coast of Flanders; they occupy also the tops of some hills and mountains of igneous origin, and they certainly offer no prospect of return for labour bestowed upon them in such situations. But in the interior of a country where heath and furze once plant themselves and flourish, although there may be at first little prospect of success to the agriculturist, the case is by no means hopeless; and the vicinity of clay might often be taken advantage of to bring these districts into profitable cultivation. The alumina and lime in such case may be supplied artificially, and the other inorganic constituents may often be obtained from the decayed and decomposed plants which have grown upon the spot. It is unnecessary to say that sandy beds allow the moisture to traverse them very readily, and are soon heated, so that the crops grown upon them suffer greatly from drought. This must be to a certain extent unavoidable.

Stiff clay, unmixed with a sufficient quantity of silica in the form of loose sand, is sometimes extremely difficult and troublesome to bring into cultivation. The chief want in this case to be supplied is that of lime; for there is always abundance of silex, although not in the best or most convenient form.\* The stiffest clayey beds, when dressed with

\* It is a fact not a little interesting, that sand thrown by the sea on the coast of Cornwall is very extensively employed in the interior of the country for agricultural purposes. Vast quantities of this sand (estimated at one hundred thousand tons) are annually taken from Padstow harbour to the interior; and this cannot be considered more than one-fourth part of the whole quantity removed. Between five and six millions of cubic feet of sand are thus annually conveyed from the coast, and spread over the land in the interior as mineral manure. In this case, however, the sand is not siliceous, but consists almost entirely of comminuted sea-shells, and thus affords the requisite supply of carbonate of lime to the clayey lands of the interior.—De la Beche's Report, &c. p. 479.

lime, are readily made to bear valuable crops ; but, as the clay is exceedingly retentive of water, and yields it back to the atmosphere with great difficulty and very slowly, it is often necessary that artificial drainage should accompany whatever other method may be adopted for the bringing such soils into cultivation.

Limestone, when pure, or nearly pure, as in the state of chalk or crystalline limestone, is often a barren rock ; and this is especially the case when it is exposed on a hill-top, where the rain is unable to transport those argillaceous portions which have been washed from adjacent clayey beds. An admixture of clay, however, converts decomposed limestone or chalk into marl, and in this state it becomes an admirable soil.

Magnesia is a very common, and almost necessary, constituent of soils ; and it is worth while remarking here, that the lime and magnesia, as well as the potash and soda found in soils, are all of great importance, and form bases which, when mixed with oxygen, are in a condition to be absorbed by plants to whose growth they are essential. None of these earths however alone, nor indeed any two of them, even when associated with carbon, are sufficient to form a productive soil ; and, besides being mingled in the proper proportions, it is necessary also that the mixture should possess a proper texture, adjusted to the quantity of rain that is likely to fall ; for without this the air is not properly supplied to the root of the plant, and the process of oxidation, effected during the slow decomposition of this air, and upon which the growth of the plant seems to depend, does not commence, so that the plant is either parched for want of moisture, or stifled for want of air. As a general rule, it has been noticed that more rain falls on mountainous districts than in plains ; and this exactly answers to the usual

position of clayey soils in plains and valleys, and a freer and more open soil on the high ground.

With regard to the relative value of different geological formations in agriculture, it will be evident, from what has just been stated, that no general rules can be laid down ; and that, as it is rather the mineral and physical character than the geological age, the determination of which is important, the Geologist can only bring his knowledge to bear in any given instance when he has informed himself of the actual structure of the district. In our own country, the older rocks are frequently barren, in consequence of the absence of limestone ; but where that is present, and there is a due admixture of silica, argil, and limestone, as in some of the Silurian districts, and some parts of the Old red sandstone, a strong and excellent soil is obtained. The Old red sandstone, both in Herefordshire, and elsewhere where its texture is good, is often exceedingly productive.

The soil which covers the strata of the carboniferous or newer Palæozoic period is rarely of great value for agricultural purposes, owing to the preponderance of crystalline limestone in a condition which resists decomposition, and the almost uniform absence of argillaceous beds, except in the upper part, and associated with the coal measures. In these latter beds, however, the presence of argil does not tend to render the land productive, so that the whole series of these rocks is poor and valueless so far as the surface is concerned. Fortunately their mineral treasures beneath the surface far more than make up for this deficiency. The culm measures of Devonshire do not form an exception to the general agricultural condition of the upper carboniferous beds in other parts of the British Islands.

The Magnesian limestone, overlying the coal measures, and covered up by the beds of the New red sandstone, is

not uniformly valuable for cultivation ; but some of the districts where it preponderates are remarkable for being the best and richest grazing districts in the north. The magnesian limestone, if burnt, and used on the soil, is, however, extremely injurious, remaining for a long time in the same state, and seriously checking all kinds of vegetation.

The New red sandstone, although not so thick as many of the older beds, covers a very large tract of England, and is remarkable almost everywhere for its great fertility. It consists of sandstones and sands, for the most part of loose texture, and alternating with innumerable beds of marl ; and these are most abundant in the upper portion, which is not unfrequently characterised by a strong marly loam. Hence it arises that the latter, being the stiffest and most clayey bed, is usually employed as arable land ; while the remaining portions are admirably adapted for pasture, and are celebrated in some parts of the country for the excellence of the hay grown upon them.

The Lias, with its associated marlstone, varies from a cold, wet, and extremely tenacious blue clay, to a strong and valuable clayey loam, and its value in an agricultural sense depends on the proportion of limestone and marl associated with it. In the upper part, where the sands of the inferior oolite rest upon it, they are sometimes turned in, and mixed with advantage ; but there is always in such case a want of drainage, and the soil remains cold. The principal part of this formation is in old pasture, and forms the dairy districts of Somerset, Warwick, Leicester, &c.

The Oolites (including the Wealden) consist of so many alternations of calcareous beds with sand and clay, that they offer almost every variety of soil, and are throughout capable of the highest cultivation. Where the limestone is too prominent (which is sometimes the case), the clays



are generally at hand to correct the evil; and the clays, if sometimes too stiff and tenacious, require only a thorough system of drainage to furnish the best and richest crops of wheat that can be grown in our island. The great Oolite is, perhaps, the bed least readily turned into cultivation, and this arises from the small quantity of carbon it retains upon its surface.\* The Wealden beds, also, are apt to form into hard pasty masses, into which the roots of vegetables penetrate with difficulty.

The beds of the Cretaceous group vary much in agricultural value: the lower beds, those of the lower greensand, are often exceedingly rich and capable of the highest cultivation, and the upper chalk forms extensive downs, which are well known for their short sweet herbage, supporting large flocks of sheep. The lower beds of chalk are without flint, and are often mixed with alumina, which converts them into a rich and valuable marl; while the soil at the junction of this marl with the upper greensand is a very productive loam, making an excellent corn land.

The lower greensand, although in some parts of the country, as in Bedfordshire, exceedingly rich, occasionally supports only an imperfect, heathy vegetation, but it is not unlikely that careful cultivation, and the mixing of soils, may ultimately render this also productive.

The Tertiary beds of England consist chiefly of the ar-

\* With regard to the capability of the Oolites for cultivation, I need only remind the reader who is acquainted with the middle of England, of the varied and rich woodland scenery in some parts of Oxfordshire, Northamptonshire and Gloucestershire, where the hilly character of the ground is derived from the successive escarpments of the Oolites. The views from the Cotswold hills, (the hard beds of which are themselves capable of the highest cultivation, when a moderate share of time and money is judiciously expended on them,) and the fine scenery to be enjoyed by any one who will *cross the country* in search of it, (for that is necessary,) will most richly repay any trouble that the exertion may cost; and no one can have a correct idea of the physical features of the Oolites in the middle of England without thus journeying over the country in search of the picturesque.

gillaceous beds filling up the basins of London, Hampshire, and the Isle of Wight, together with the diluvium of Norfolk and Suffolk and other districts in the east of England. The crag, although interesting in a geological point of view, covers but a small tract of country.

The lower beds of the London clay, consisting of a plastic clay associated with sand and gravel, present every degree of fertility between the extremes of a poor and worthless soil, where the gravel prevails, and a wet, cold soil, where the clay is unmixed : where, however, the gravel and sand have sufficiently tempered the clay, and the land is free from springs, a rich productive loam is often met with. The London clay itself is for the most part tough and tenacious, but is much improved by an admixture of sand.

The diluvial deposits under certain conditions, as in Norfolk and Suffolk, are sometimes rendered exceedingly productive ; but in other districts they consist too entirely of fragments of flints, and hard siliceous and other rocks, to be brought into profitable cultivation. In the county of Norfolk, however, the worthless sandy and gravelly soil of this kind resting on chalk and chalk-marl has been so far improved in texture and quality by mixing, that the rich and valuable land of that county may almost be said to have been made by artificial management.

It will be seen, therefore, that there is on the whole a uniformity of agricultural character affecting even the sandstones, limestones, and clays of each geological period, and that, *ceteris paribus*, the amount of fertility to be anticipated from any particular rock may be to a certain extent decided by a knowledge of its geological position.

Before concluding this chapter, I would add a few remarks on a subject of considerable interest immediately bearing on what has been said : I mean, the determination

of the value of land, and the advantage of an adequate knowledge of Geology in attaining this result.

Where an estate is situated on several beds cropping out in succession, and of different agricultural value, a person ignorant of Geology would be greatly puzzled to determine the value of the estate ; and it would present appearances extremely different if the surveyor first walked across it in the direction of the dip, and afterwards on the strike.

In order to obtain a true notion of the value, subdivisions of the property must be made, and the arranging these would be greatly facilitated by knowing the lines of out-crop of the different strata. But, besides enabling the land-agent to do this, and to identify the various soils, with the general productiveness of which in other places he should be acquainted, Geology would point out what land is in a forced, exhausted, or ordinary state of cultivation ; while from the mineral structure of the subjacent rock the composition of the soil may be inferred, and any substance detrimental or favourable to vegetation be detected.

“ A surveyor, therefore, should be acquainted with the nature and extent of the geological formations, especially those in the more immediate sphere of his duties ; and in acquiring, as well as applying this knowledge, he would be much aided by good geological maps. He should, also, make himself thoroughly acquainted with the relative productiveness of the soils on these formations ; and in valuing an estate, he should observe the texture of the soil and sub-soil, — the dip and compactness of the strata, — and the form of the surface of the land ; all these circumstances greatly affecting the value of landed property.” \*

\* “ Whitley’s Application of Geology to Agriculture,” p. 143. I must again acknowledge my obligations to this book, which has greatly assisted me in the preparation of the present chapter.

## CHAPTER XV.

AGRICULTURAL GEOLOGY *continued*.—THE NATURAL AND  
ARTIFICIAL DRAINAGE OF LAND.

IN describing the different kinds of soil and subsoil that are occasionally met with, I had occasion in the last chapter to allude to the subject of drainage ; but I intentionally reserved all explanation or consideration of the matter till it was introduced regularly before the reader, as a distinct branch of Agricultural Geology. The various methods of natural and artificial drainage of land, so far as they bear upon Geology, will be the subject of the present chapter.

The drainage of an island or continent is effected, under ordinary circumstances, by means of a gradual and usually gentle inclination of the surface of the country towards the coast-line of the sea which bounds it. The rain which falls on the various parts being conducted by channels, or rushing down the hill-sides into brooks, is by them conveyed to the neighbouring rivers, and these, descending into and traversing the plains, at length reach the sea ; the rate of motion of the waters in all these channels necessarily depending on the amount of the fall, and the relation it bears to the distance traversed during the whole course of the stream from the high ground to the sea.

Now there are two points in this statement which deserve attention, namely,—first, that the rate of motion, or the velocity of the current, has reference to the distance

traversed, as well as the amount of fall ; and next, that after the water has been conducted to the foot of the hills, in which it is chiefly collected, it frequently has to traverse a large extent of country nearly horizontal, or in which the descent towards the sea is hardly appreciable. Both these points must be evident to every one who considers the subject ; for the latter is simply a statement of fact, which may be verified by referring to almost any map ; and the former is equally clear ; for if a river has to traverse a certain tract of country in a direct line to the sea, with a given amount of fall,—then if the distance traversed is increased by means of the sinuosities of the channel through which the water is obliged to pass, the rate of motion must evidently be diminished.

In those cases in which an extensive tract of nearly flat land (its elevation not being much above the level of high-water) is traversed by a number of streams, nearly stagnant for want of a sufficient fall to carry off the water, there is an evident tendency to form swampy and marsh land, and the slightest accident may at any time produce this result, and lay under water a whole district. Such is the condition of the fen-lands in the East of England, and such also is in some measure the case with those parts of Holland near the Rhine, and with the land at the mouths of many other rivers in all parts of the world. The practicability of effectually draining and bringing into cultivation these lands is one of the subjects to be discussed in the present chapter.

But there are other cases of a totally different kind, in which the long continuance of moisture on the soil is exceedingly injurious, and prevents cultivation. Among the most remarkable of these must be ranked those numerous instances of peat-bog which are so common in Ireland, and

in many other countries, where the water is retained partly or entirely beneath a thick tough coating of vegetable soil, made up of the matted roots of plants. The drainage of bogs in this condition requires, as may be supposed, a process quite different from that which would succeed with fen-lands; and most of the cases in which it is required to improve land by drainage will be found to refer either to the class just described, or to that of which the fens offer the best example.

These two, in fact, include the different methods of surface drainage; and, after explaining the circumstances under which one or the other of them may be pursued, I shall add a few words, in conclusion, with respect to another part of the subject, involving the consideration of the drainage of strata, and the means by which deep cuttings, tunnels, and other engineering works, are rendered secure.

Before proceeding to the consideration of those contrivances by which drainage can be artificially effected, it will be useful to see how Nature herself has arranged in ordinary cases, which are offered as it were for man's imitation, and which leave so little comparatively to be done by man in rendering the earth a fit receptacle for those plants and vegetables that are required for his sustenance and enjoyment.

The very fact of stratification itself, and the manner in which the subsoil and the soil are derived by decomposition from the underlying rock, afford a ready explanation of the well-drained condition of the soil in any district that is tolerably fertile. Drainage is indeed a natural result of the existence of alternating strata of different materials, some (as sandy beds) allowing water to penetrate them freely, others (as the clays) resisting its passage, and others again (as the limestones) admitting the water by numerous

cracks and fissures into reservoirs and subterraneous caverns, but not absorbing it except near the place of contact, and remaining elsewhere dry and unchanged.

All these different beds occurring at intervals, and being covered up by the subsoil, which rarely resists the passage of water through it, the surface-water, when in excess, penetrates into the subsoil, and is thence carried down till it reaches a permeable stratum, where it is absorbed and swallowed up, unless, indeed, as sometimes happens, this bed is already sufficiently loaded with water, and can no longer receive it. There are thus two very different conditions under which the natural soil of a district may be rendered infertile by the presence of stagnant water, and in like manner there are two ways in which drainage may be effected, the one of which is called surface and the other deep-draining. By the former is meant the carrying off the water by drains cut upon the surface, while the latter depends rather upon the geological condition of the underlying rock.

It rarely happens that a large tract of land is so far injured by the presence of stagnant water as to become fen-land or swamp, except when the soil and subsoil, and even the subjacent rock, consist of tough stiff clays, spread over the country nearly at a dead level. Such is the case with the fen-lands of Cambridgeshire and Lincolnshire, where the Kimmeridge and Oxford clays are in contact, (the intermediate calcareous bed being absent,) and are of great and unknown thickness. These beds, therefore, extending over a very considerable tract of country and being totally impervious to water, barely admit of complete natural drainage, because there is hardly sufficient fall to carry off the surplus water, which they obtain partly from the atmosphere, and partly from the numerous streams which

come into them from the oolitic beds on the west and north, and from the chalk and greensands on the south and east.

There are eight principal rivers traversing this district, and these empty themselves into the sea by three main trunks, (the Welland, the Nene, and the Ouze,) at Boston, in Lincolnshire; Wisbeach, in the Isle of Ely; and Lynn, in Norfolk; all of them situated near that remarkable shallow bay, called the Wash. There can be little doubt that the whole of the fen district has been at one time in the condition of the Wash, and that afterwards it was for a long period constantly subject to inundation from the sea, but during this time large portions of it were in all probability permanently covered with sheets of water, some of which (as, for instance, the fresh-water lake called Whittlesea Mere) still remain. Even so lately as during the wars which followed the conquest of England by the Normans, the Isle of Ely (a small outlier of the lower greensand resting on the Kimmeridge clay) was literally an island and quite surrounded by water; although afterwards, in the reign of Stephen, the neighbouring country is said to have been "one of the most fertile in England."\* However this may be, it is probable that for several centuries after this time the district was subject to the incursions of the sea; although, as the level of the country is slightly above that of high water, the rivers which traverse it were capable, under ordinary circumstances, of effecting a certain imperfect drainage. It was required, however, in order to render the soil permanently valuable, that some system should be devised for its complete drainage; and the most obvious course would have been to scour out, widen, deepen, and straighten the rivers and the tributary streams,

\* Wells' History of the Drainage of the Bedford level, vol. i. p. 67.



and embank their sides, and then to convey into these streams the waters that were retained in the intermediate tracts by a system of drains, out of which the water could be lifted by pumps worked by machinery, (wind-mills, steam-engines, &c.) This method was the obvious one under the circumstances, and would, no doubt, have proved perfectly successful, had not the undertaking been unfortunately commenced under the plans of a Dutch engineer, (a Colonel Vermuyden,) whose knowledge of draining was confined to the methods in use in Holland and Flanders, where the general level of the greater part of the land is below that of high water, and the sea requires to be kept out by locks and breast-gates, and a series of embankments on a stupendous scale.

The mistake thus made in the commencement of the fen-drainage has never been completely set right; for the system adopted, that of intersecting the district with a number of straight drains, without much reference to the natural outlets, has been so extensively acted on, as to render it almost impossible to expect that a good natural system could now be carried out.

The artificial system at present adopted may be thus explained. Certain proprietors of a given tract of land agreeing together, the boundary of the district is set forth, and subdivision dykes are made for draining the estate of each owner. These ditches empty themselves into a main drain, (cut at the general expense of the owners,) which runs through the whole district, and is well embanked. This terminates at one end near a river, on the banks of which machinery is erected, (in many cases a steam-engine), by which the water is lifted and discharged into the river, whence it passes by the nearest course to the outfall, and so to the sea. The circuitous course taken by the rivers is

avoided in some cases by stupendous cuttings, and the water is thus conducted as rapidly as possible, the sea being kept out by sluice-gates at high tides, and the gates being opened to allow of the outlet of the water when the height of the sea admits of it.

The draining of extensive tracts of fen-land is a work of such magnitude, and of expense so enormous, that it ranks among the most important of engineering operations. But this is not the case with other kinds of drainage, which are sometimes confined to much smaller districts, and occasionally even to small portions of a single property. These latter also depend more immediately on local peculiarities of geological structure, and admit of many ingenious contrivances, suggested by the nature of the underlying strata, and their order of arrangement. A few instances will best illustrate the nature of these contrivances.

The existence of peat-bog, so remarkably abundant in Ireland that it is said to cover one-tenth of the whole surface of the country, is entirely owing to the presence and accumulation of vegetable matter, several of those plants which inhabit moist situations assisting in its formation. It occurs on the faces of declivities in mountainous regions, where there is much moisture, and attains also an enormous thickness in low grounds, where, however, it owes at least half its volume to the presence of water. The water in these cases is retained beneath the surface of the bog, which often shakes and yields under pressure; and sometimes, after a wet season, the bog will burst, owing to an excess of fluid raising it to an unusual height. In such cases, a stream of black, half-consolidated mud, pours out with greater or less velocity, and has occasionally been the cause of very serious and fatal accidents.

It will be manifest that a district in which such a sub-

stance prevails is not very well adapted to become cultivated land; but it is interesting to find that, by taking advantage of geological structure, there may in some cases be a possibility of reclaiming bogs, and rendering them available for supplying the wants of man.



DRAINAGE—BOG DRAINED BY PIERCING THE UNDERLYING RETENTIVE BED.

In the above diagram (*a*) represents a bog resting on an impermeable bed (*b*), which may be of stiff clay, and which in its turn rests on a porous, sandy, or gravelly bed (*c*). By piercing the bed (*b*), and sinking such a number of bore-holes or shafts as may be necessary, the uppermost bed may be drained through the clay, which, being afterwards turned up and mixed with the peat, will form an excellent loam for most purposes of agriculture.

Another somewhat remarkable instance of drainage, effected naturally by means of the irregularities of an under surface of chalk, is quoted by Sir H. De la Beche,\* and is represented below. The chalk is here covered, but not en-



NATURAL DRAINAGE BY THE IRREGULARITIES OF THE UNDERLYING ROCK.

tirely, by a bed of stiff clay, and over this is a soil composed partly of gravel and partly of clay. Those portions of the surface near the places where the chalk projects through the clay are well-drained and fertile, the chalk absorbing that portion of the water which sinks below the surface to

\* "How to Observe. Geology," p. 289.

the bottom of the gravel. In other parts, removed from these peaks, the subsoil drainage is imperfect, and the soil is barren. Such a contrivance may sometimes be imitated artificially.

I have already mentioned an instance in which a bog may be drained by piercing through a bed which is impermeable into one below, which allows water to percolate through it. I now subjoin a section exhibiting a similar contrivance, where the object has been to drain a stiff clay which is not too thick, and which rests on a group of strata



DRAINAGE—A STIFF SOIL DRAINED BY SINKING INTO THE UNDERLYING BED OF GRAVEL OR SAND.

amongst which there are sands. In the diagram, sinkings as at (*a*, *b*) may often be attended with beneficial results, the drainage can certainly be effected by such means unless, indeed, as in the former case with regard to the bog, the lower sand is already full of water. Even in this case, however, the water may sometimes be discharged at a natural or artificial cutting, laying open a lower portion of the sand as at (*c*).

Besides the ordinary conditions of stratified rocks, the faults, or results of the disturbances of strata, may also occasionally assist the agriculturist in the drainage of land, for some of these faults are pervious to water, and act as main drains to large portions of country, while others, again, are filled with clay, and keep in the water on one side of the fault, preventing its passage to the other. In either case advantage may often be taken of the fault by any one possessed of an adequate knowledge of Geology.

As a fit conclusion to this part of the subject, in which I have considered drainage as connected with agriculture, I append, in a somewhat abridged form, some interesting remarks offered by Mr. Johnson in his *Lectures on Agricultural Chemistry* (p. 440).

The advantages of drainage to the agriculturist are numerous and manifest. In the first place, it carries away rapidly the superfluous moisture, moderates the natural dampness of the climate in a wet, boggy country, and is equivalent, therefore, not only to a change of soil, but also to a change of climate, both with reference to the growth of plants and the health of the population.

Drainage produces, also, the effect of an actual deepening of the soil, as it facilitates deep ploughing, and permits a greater absorption of useful moisture, and useful mineral salts, or organic matter, while it is also the means of noxious mineral compounds, such as the salts of iron, being diffused equally and harmlessly through the soil, or carried away before they have time to form those ferruginous compounds which are injurious as an impervious subsoil.

Drainage also alters the direction of the currents which occur in wet soils, the roots of plants obtaining their moisture from the rain which falls on the surface in drained lands, whereas in deep, swampy ground, their spongioles are only supplied with exhausted subsoil water.\*

Lastly, it is a necessary preparation to many other means of improvement which may be applied to land, and must in all cases be preliminary to every kind of building and engineering work, as no foundation can be stable,

\* This is the more important, if, as Liebig supposes, the nitrogen required by plants is supplied in the form of ammonia by rain-water. At any rate it is certain that the rain carries down in solution those nutritive substances that may exist near the surface of the soil, and these could not be supplied to the plant in any other way.

and no situation good, in which the water is allowed to remain and accumulate on a retentive soil.

The process of deep draining differs from that of surface draining already described, and has for its object a somewhat different result. It is also connected with the subject of road and canal-making, and requires to be understood and carefully attended to by the engineer, for without such attention a canal may be useless, after all the expense of construction has been incurred; and a line of road may be so dangerous as seriously to interfere with the traffic upon it.

The drainage of strata, one of the operations involved in the process now under consideration, necessarily requires an intimate knowledge not only of the geological structure of the particular district to be drained, but also of the general principles of Geological science; and Mr. William Smith, who at the close of the last century had made himself much more accurately acquainted with the actual order of superposition of the Secondary strata in England than any person then living, was also one of the first to apply this knowledge to important practical purposes. About the year 1800 his reputation for "draining on new principles" was thoroughly established in the West of England, and on the occasion of numerous landslips taking place near Bath, he was employed to prevent, if possible, a recurrence of this mischief, which he effected by tunnelling into the hill on which the land was slipping, and intercepting the springs, and then providing a direct and convenient channel, by which the water could be discharged.

In the year 1811 Mr. Smith was again employed to report on a subject of practical science connected with the drainage of strata. About that time numerous canals were being cut in different parts of the West of England,

and these, crossing the oolitic hills, were found to be particularly liable to accidents of leakage, being cut through open jointed, and sometimes cavernous rocks, alternating with water-tight clays. In the passage across the former rocks, and more especially when the summit level of the canal occurs in them, the water escapes almost as fast as it enters, and all the skill of the engineer in puddling, and making an artificial bed, is sometimes exerted in vain, and cannot prevent great and ruinous loss. But the existence of open joints and caverns is by no means the only, nor, indeed, the greatest source of injury, for innumerable small faults or slides traverse the country and confuse the natural direction of the springs, rendering them short in their courses, and uncertain and temporary in their flow, weakening by their irregular pressure every defence that may be opposed to them, and causing leaks, which let through a portion of the water contained in that level of the canal.

The general remedy for all these evils was understood by Mr. Smith, and proposed by him for adoption. It is "the entire interception of all the springs which rise from a level above the canal and pass below it through natural fissures and cavities. This is a process requiring great skill and extensive experience; some of the springs for instance which it is most important to intercept come not to the surface at all in the ground above the canal, but flowing naturally below the surface through shaken or faulty ground, or along masses of displaced rock which extend in long ribs from the brows down into the vale, emerge or attempt to emerge in the banks of the canal; these no ordinary surface-draining will reach, and none but a draining engineer, well versed in the knowledge of strata, can successfully cope with such mysterious enemies. But Mr. Smith, confident in his great experience, not only proposed,

by a general system of subterraneous excavation to intercept all these springs, and destroy their power to injure the canal, but further, to regulate and equalize their discharge, so as to render them a positive benefit. This he would have accomplished by penning up the water in particular natural areas, or pounds, which really exist between lines of fault in most districts, or between certain ridges of clay ('horses,') which interrupt the continuity of the rock, and divide the subterranean water-fields into limited districts, separately manageable for the advantage of man by the skilful adaptation of science." \*

This account of the nature of the work required in subterranean drainage is so much to the purpose that I need add little further in illustration of the subject. The principles involved must in most cases be nearly the same, and whether it is required to prevent a canal from leaking, or a deep cutting or tunnel from being drowned, or whether, finally, it is the object to prevent that washing away of a thin intermediate stratum, by the absence of which an upper bed will be enabled to slide upon a lower one and produce a landslip, the general nature of the contrivances to be adopted differs but little, although the particular method must in all cases be strictly adapted to the special conditions involved, and must vary in every district. It is only by a clear and accurate comprehension of the actual cause in each instance, that the draining engineer can hope to succeed, whether in combating an evil that already exists, or preventing an accident that is foreseen.

Besides the application of the principles of draining on a large scale, it is often important in cuttings of moderate depth, when made in stiff clayey beds alternating with occasional sand, to provide against the danger of slips. This

\* Professor Phillips' *Life of William Smith*, p. 69.



can only be done by thoroughly and effectually draining the whole of the clay near the exposed surface. For this



SECTION OF A RAILWAY CUTTING. WATSON'S PATENT DRAINAGE.

purpose a method indicated in the above diagram has of late years been introduced, in which a number of perforated cast-iron draining-pipes are inserted into the clay sides of the cutting for about twenty or thirty feet, each pipe slanting towards its open end, so that the water which passes into it is immediately drained off. It is found by experience that the holes for the pipes, being made by a boring machine which simply cuts away the material without hardening or polishing the natural substance of the clay, the water drains freely into them in wet weather; and when the weather is dry they permit the clay around them to dry also, so that in this way a system of cracks and fissures communicating with one another is established in the clay, by which the whole of it is drained thoroughly to a considerable distance from the surface of the cutting. The efficacy of this system has been proved in the troublesome cutting in the London clay between the Camden Town and Euston Square stations of the Birmingham railroad, where the water was found to trickle from these pipes after they had been for some time inserted, although at first they remained perfectly dry.

## CHAPTER XVI.

AGRICULTURAL GEOLOGY *continued*.—THE PHENOMENA OF  
SPRINGS AND WELLS.—ARTESIAN WELLS.

IF, as we have found in the last chapter, an excess of water remaining undrained upon the earth's surface is highly injurious to that kind of vegetation which is useful to man, the absence of a proper and sufficient supply of moisture is no less a cause of infertility, so that a knowledge of the circumstances under which springs naturally rise out of the earth is of great value to the agriculturist, more especially if by such means the existence of springs, and of subterraneous reservoirs of water, can be predicated in any particular district.

A knowledge of this kind is also quite as necessary to the engineer and the architect, as to the agriculturist, for it is not unfrequently the case that the selection of a site for building, or of a line of road or canal, may be greatly influenced by the probability, or otherwise, of springs of water being tapped.

The atmosphere is well known to be the main agent employed by Nature in the distribution of moisture upon the earth, absorbing a considerable quantity of water in its passage over the sea and afterwards depositing it in the form of rain, owing to changes which take place in its temperature, and, probably, in its electrical condition. Of the quantity of rain, however, which falls upon the earth in a

given spot, only a small proportion finds its way to the sea directly and immediately, by means of rivers ; and it has been calculated by M. Arago that this proportion in the valley of the Seine is not more than one-third. Of the rest, some portion is, no doubt, re-absorbed by the atmosphere, and some enters immediately into the composition of plants and animals ; but a large quantity remains, and this descends into the bowels of the earth by means of those strata which are permeable to water, and it is either retained in them until they are full, and then poured over their edges into the neighbouring country, to feed the nearest stream ; or is discharged in the form of perennial springs, where the containing stratum is exposed on a hill-side ; or, lastly, is accumulated in subterranean sheets and reservoirs, whence it is only discharged by some natural or artificial communication being made to the surface at a lower level.

Let us, however, trace a little more minutely the course of that portion of the rain-water which descends beneath the surface of the earth, and let us do this with reference to the order of arrangement of those various substances of which the superficial crust of the earth is made up. We shall in this way discover the *rationale* in each variety of circumstance under which the springs occur.

It will be evident, on a little consideration, that as there are different circumstances under which springs of water rise through the superficial crust of the earth and make their appearance at the surface, these must, in all probability, have reference to different conditions of the strata. It will, in fact, be found that this is strictly the case, and that the occurrence of springs is, in every instance, a phenomenon which it requires a thorough knowledge of Geology to illustrate and take advantage of. I will explain shortly the nature of these various kinds of

springs, and the geological conditions necessary for their existence.

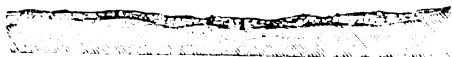


ILLUSTRATION OF THE OCCURRENCE OF LAND-SPRINGS.

1. *Land Springs*. — One of the most common cases in which springs of water make their appearance along a line of country, and generally on a hill side, is exhibited and explained by the above diagram, in which there are three strata represented; the lower and upper of which are supposed to be impervious to water, while the middle one allows the water to permeate readily. The water, draining into this middle bed, is conducted along, until it reaches a spot, as at c, where it is laid open by the structure of the country, and where the water escapes into the valley, of which the diagram is a section. In this case the outcrop of the permeable stratum is readily distinguished after rain by the line of springs which accompanies it; but these springs, and therefore the indications they offer of the bed, often disappear in dry weather. It happens also occasionally that the spring, although flowing, is not immediately exposed, but is covered up with gravel or vegetable soil or perhaps by an impermeable subsoil, but it may then be obtained by sinking a well, and may sometimes be found bubbling up in a natural well, which it has formed for itself.

It is not always, however, that these natural wells, or those which are artificially obtained by shallow sinkings into the subsoil or the gravel, are the result of any distant draining, and occasionally the water which falls in a district is collected into the hollows of the nearest retentive stratum, and may be obtained by simply sinking down a

few feet to meet them. This is illustrated in the annexed diagram, where the hollows are supposed to be occupied by



a loose gravel, and covered by a tough but non-retentive coating of soil and subsoil. The water that falls on the district sinks at different places into the gravel, and is there preserved from evaporation, and may be obtained readily, but is rarely to be depended on after a continuance of dry weather.

The diagram in page 511, besides illustrating the nature of common springs at the outcrop of a bed, also explains an appearance which has sometimes been thought very unaccountable. An instance occurs in the valley of the Thames, near Richmond, where the river (which is there affected by the tides) has its channel cut in the London clay, part of which is a stiff clay, and part of it a loose gravelly sand (see diagram, *b*). It is found that many of the wells in the neighbourhood that are fed by the so-called land springs vary in height during the day, without reference to the weather, and are constantly rising and falling. This arises from the manner in which these wells are supplied, for they are sunk to the sandy bed which communicates with the river, and the water, therefore, rises and falls with the flux and reflux of the tide. A vast number of the irregularities to which the flowing of ordinary springs is subject may be explained in like manner by local circumstances, or by some peculiar geological conditions.

2. *Regularly flowing springs of cold water, connected with, and arising from, faults.* — The class of springs pro-



ILLUSTRATION OF THE PHENOMENA PRODUCING SPRINGS ON A LINE OF FAULT.

duced by the existence of those simple displacements of strata, called "faults," includes a vast number of cases in many limestone districts, and more especially in those of the carboniferous period, which in England are usually the most disturbed. So numerous, indeed, are these cases, that, according to the observations of Mr. Hopkins in Derbyshire, every instance of a spring was accompanied by independent evidence of the existence of a fault, and in these districts the line of springs more frequently marks the fault than the regular baset of the stratum. The cause is simple, and will be at once understood by referring to the above diagram, where the middle of the three beds is supposed to be permeable, and the other two retentive. The water stopped at the fault rises to its own level, and generally makes its way out at the surface; but it is manifest that under certain circumstances it may again make its way into the permeable bed, by the fracture of which its course was changed; and if so, it may ultimately come out at a hill side as an ordinary land spring.

3. *Thermal and Mineral Springs.* — Springs of water containing mineral matter, either in mechanical suspension or in solution, are common in many parts of the world. It has been found in almost every instance of this kind (or, at least, whenever from its unvarying temperature the water appears to have come from such a depth as to be more or less independent of atmospheric changes), that the average, or constant temperature is above the average annual temperature of the place at which the spring comes to the surface. It is also the case that, with very few exceptions,

no variations of external temperature manifest themselves in the thermal springs of a district, and that in all such exceptions the excess of heat is inconsiderable, except where volcanic operations, going on at the present day, have been the manifest causes to which the change must be referred. Besides the mineral matter contained by thermal waters, it is not unusual for large quantities of gas to be constantly evolved from such springs; carbonic acid gas being both the most frequent and the most abundant.

With regard to the geological phenomena accompanying springs of this kind, they are extremely interesting, and the observations concerning them are already sufficiently numerous to enable us to state the general result. It is certain that by far the greater number of them arise in the vicinity of some great subterranean disturbance either connected with volcanic action or with the elevation of a chain of mountains, or, lastly, with clefts and fissures caused by disruption. In illustration of this, it is only necessary to mention the remarkable districts of Matlock and Bath, in our own country, where thermal springs appear accompanying great natural fissures in the mountain limestone. This is also observable with regard to the hot-springs of Wiesbaden and Ems, near the Taunus chain; of Aix-la-Chapelle, near the Eifel; of Carlsbad and Tœplitz, near the Mittelgebirge, in Saxony; of Central France, in the extinct volcanic district of Auvergne; and of various places in the Alps, the Apennines, and the Pyrenees.\*

Among the most remarkable and the grandest phenomena of this kind must be ranked those magnificent fountains of boiling water, which are known to burst forth

\* I have not space here to dwell on the peculiarities of geological position of these and other celebrated localities of hot-springs in Europe. They are all contiguous to remarkable dislocations, to great lines of elevation, or to active volcanic centres.

at irregular intervals in several parts of the volcanic plateau in the middle of Iceland; and these, although they exhibit but little analogy with the ordinary phenomena of thermal springs, must not be passed by without notice, since the accounts that have been given by different visitors vary so considerably as to leave no doubt that the prevalence of volcanic action in the district is constantly effecting great changes.

The best known of the Icelandic hot springs are called the Geysers, and they form a group of wells situated in a valley about a mile broad, the bottom of which is a marshy meadow through which several small brooks wind their way. On the south side of the valley the three snow-clad peaks of Hekla tower above the rocky wall which bounds the plain; and on the north side is a hill, about three hundred feet high, separated by a narrow defile from the adjoining mountains. A little south of this elevation (which slopes gently towards the level ground) lie the far-famed fountains, and more than fifty of them can be counted within the space of a few acres. They are of two kinds; the one filled with hot water as clear as crystal, the other giving vent to warm vapours, occasionally accompanied by a little muddy fluid; and these last are confined to the summit or acclivity of the hill, whilst the others are only found in the plain at its foot.

The most remarkable of these singular fountains is sometimes called 'the Geyser,' to the exclusion of the rest, and is situated on a mound of siliceous tufa, formed from its deposits, about thirty feet high and two hundred feet in diameter. On its summit is the basin, sixty feet across, and six or seven feet deep, the bottom of which terminates in a pipe ten feet wide at the mouth, but gradually narrowing to seven or eight feet, in a perpendicular descent of nearly



twelve fathoms. The interior both of the basin and the pipe is smoothed and polished by the constant friction of the hot water, which rises in small jets every two hours. Between the intervals of the jets the water only half fills the basin, and remains quite still, at a temperature of 154° Fah.; but, at the depth of sixty feet, the temperature has been said to amount to 255° Fah.

The great eruptions of this fountain seem to take place once in about twenty-four or thirty hours, but not with any regularity, the discharge being greatly affected by the eruptions of the neighbouring volcano, and the periods having frequently undergone great change. In the account from which I chiefly quote,\* the eruption is described as being preceded by a hollow rumbling sound, and a number of explosions, accompanied by a violent quivering motion in the ground. The author then states, that having been driven from the spot by this movement, he turned at a little distance, and beheld a thick pillar of vapour shooting like an arrow to the clouds, and surrounding a body of water, which rose with a fluctuating motion to the height of eighty or ninety feet, some portions of the fluid rising even above this, or streaming in arches from the cloud. Sometimes the steam divided, and exhibited the aqueous column shooting upwards in innumerable rays, spreading out at the top like a lofty pine, and descending in fine rain; at other times it closed in thicker darkness round the centre, veiling it from the eyes of the spectator.

The eruption continued about ten minutes, when the water sank down into the pipe, and the whole was again in repose, the basin being completely empty, and the water far down in the pipe, and slowly ascending. In other in-

\* Krug von Nidda, Karsten's Archiv. ix. 247. See the account of Iceland, Greenland, and the Faro Islands, in the Edin. Cab. Lib. 1840, p. 59.

stances, clouds of steam have continued to escape long after the eruption of water has ceased, and the eruption has then been observed to close, as it began, with a loud explosion.

It is a fact worthy of remark, that the numerous thermal springs grouped together in the valley of the Geysers appear to be quite unconnected with one another, each having its own interval between the eruptions, and several of them sometimes playing at once; while occasionally a considerable period will elapse without any of them boiling up, or exhibiting any feature of activity.

Several conjectures have been hazarded in explanation of these remarkable phenomena. Sir John Herschel has suggested that it would be sufficient to imagine a subterranean stream of water flowing through the pores and crevices of lava, and suddenly reaching a fissure in which the rock is intensely heated. Steam would then be formed instantaneously, and, rushing up the fissure, it might force up the water with it to the surface, while at the same time part of the steam might drive back the water of the supply for a certain distance towards its source; when, after a space of some minutes, the steam was all condensed, the water would return, and the phenomenon be repeated.



THE GEYSERS OF ICELAND.

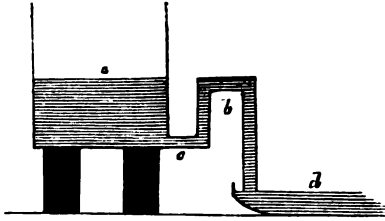
Perhaps, however, a more probable method of explaining the action of the Geysers, and one perfectly consistent with what is known of the district, is that of which the above diagram will serve to give an idea. The water from the

surface is supposed to drain gradually by numerous fissures in the lava, and through the loose scoræ, into a subterranean cavity, into which at the same time steam at a very high temperature also penetrates from below, by similar cracks in the heated rocks. For a certain time the steam is condensed into water, and the temperature of the water running into the cavity is raised, until at length the cavity becomes filled, the lower part with boiling-water, and the upper part with steam, under a very high pressure. As this pressure increases, the expansive force of the steam becomes at length so great that the water is forced up the pipe, at first gradually, but soon with tremendous violence, and the eruption takes place; the steam as it expands continuing to force up the water in the cavity, till it is completely emptied. As soon as this happens the steam also escapes, and the same thing goes on again.

4. *Intermittent Springs*.—The class of springs that next comes under our notice consists of those which, from a certain alternation of flux and reflux, not dependant upon the quantity of rain falling in the district or on the tides, have been called “intermittent.” These do not appear subject to any general law affecting the period of their recurrence; nor are they, like the boiling springs of Iceland just described, referrible to any cause in which heat is called into action. They admit, however, of a very ready and sufficient explanation, and one strictly corresponding with the geological conditions of the rocks from which they flow.

The fundamental principle involved in the explanation of these springs is a simple and well-known hydrostatical law, exemplified in the common siphon,\* and the application of it to intermittent springs is sufficiently evident.

\* A siphon (see diagram) is a bent tube, having one leg longer than the other. When this tube is filled with any liquid, and the shorter end is immersed in a



In the annexed diagram the vessel (*a*) communicates by a tube (*c*) with the siphon tube (*b*); and it is manifest that when the water in (*a*) rises above the level of the top of (*b*) it will begin to flow over, and escape as at (*d*). But as soon as this is the case the tube (*b*) begins to act as a siphon, and draws off all the water in (*a*), so that if a constant supply is poured into (*a*), but at a rate slower than the rate of the discharge at (*d*), there will be an intermittent discharge, the interval depending on the relation of the rate of filling to that of emptying.



INTERMITTENT SPRINGS.

Now let us apply this explanation to the case of a subterranean cavity in a limestone rock, slowly fed by drain-

vessel containing liquid of the same kind, the weight of the column in the longer leg will cause the liquid to begin to run out, and it will continue running till the vessel is emptied. This arises from the pressure of the air on the exposed surface of fluid forcing it up through the tube to prevent a vacuum, which would otherwise be formed at the highest point; and the extreme limit of length at which the siphon will act is therefore determined by the height of a column of the fluid equal to the pressure of the atmosphere (fifteen pounds on the square inch). This limit in the case of water is something more than thirty feet.



SIPHON.

age from the cracks and fissures of the rock above, but communicating at a distant point with the surface by a bent or siphon tube. It can hardly be necessary to do more than point out the strict analogy between this case and the one just assumed ; and there can be no doubt, from what we know of the structure of limestone rocks, that such a condition as that represented in the diagram is, to say the least, very possible.

Besides this case of an intermittent spring, in which the spring flows occasionally and is then dry for a certain period, it is yet more common to find springs which constantly flow, but are sometimes greatly increased without any apparent cause for the increase in the quantity of rain fallen in the district. It is more than probable that in such cases there is a siphon tube communicating with a large reservoir, which has another outlet insufficient to drain it completely. The periodical increase is then the result of the siphon, and the ordinary supply is independent of it.

5. *Artesian Wells*.—Artesian wells are so called from the French province of “Artois,” where, so far back as at the beginning of the twelfth century it was the custom to obtain springs of water artificially, by piercing the soil to a certain depth in places where no indication of springs existed at the surface. When, therefore, in other districts water is obtained by boring, and when, more especially, the water thus reached rises considerably in the well, the term Artesian is applied, and serves to distinguish these springs from those which flow naturally, or in which there is no tendency to rise above the level of the basin or reservoir in which the water is contained.

The hydrostatic principle involved in the existence of Artesian wells is quite as simple as that according to which the siphon empties a vessel of water. It is simply this, that

water, when forced to pursue any direction, or travel to any distance in confined tubes, will always tend to rise to the level of the open water with which it communicates, and, whenever the means are afforded, will always so rise. In the annexed diagram, if (*a*) is a vessel provided with a

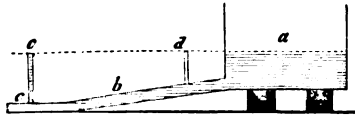


ILLUSTRATION OF THE PRINCIPLE OF ARTESIAN SPRINGS.

bent tube (*b, c*), then if water is poured into the vessel, the pressure at (*b*) (*c*) will be equal to the weight of a column of water reaching from those points respectively to the level of the water in (*a*); and if, therefore, a tube is inserted at (*c*), the water will rise in (*c*) to that level. This will be the case, also, if a tube is inserted at (*d*); the dimensions of the tubes (*c*) (*d*), and their actual length, being indifferent.

It will be understood that this is a known law of fluids, and may be proved by experiment. Let us now see the nature of the application of this law in one or two simple cases.

In the diagram given below the mechanical conditions are precisely the same as in the former one, and the only differ-

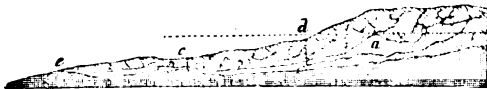


ILLUSTRATION OF NATURAL ARTESIAN FOUNTAIN.

ence is, that the reservoir is supposed to be contained in a cavity in some stratum, and the tube (*b, c*) is continued,

and is open at (*e*). At this point there will be a natural fountain, the water rising as it would if an aperture were made at the end of the tube in the former diagram. It must be perfectly clear, that if a communication is made at any point between (*d*) and (*e*) the water will rise to the surface, and even above it, and an Artesian spring will be there produced.

Again, let us take the case represented in the annexed sketch, that, namely, of a basin-shaped depression in retentive rocks, partly filled with retentive beds, which, however, admit the passage of water to their lower part. This case

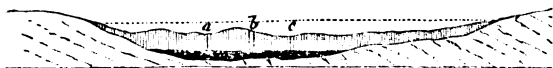


ILLUSTRATION OF AN ARTESIAN SPRING IN A BASIN-SHAPED DEPRESSION.

is, in fact, that of the London Basin, and of a large number of other basins of the Tertiary period. There will be little difficulty in understanding the action of those wells which are here dug through the retentive clays to the loose sands of the lower beds. The water accumulates at the bottom in extensive reservoirs, which, when not only they but the channels which supply them are full, exert a pressure on the overlying beds proportioned to the height of the column of water, measured from the level of the water in these channels to that of the contact of the clay-beds with the underlying chalk, where the lower sandy beds come to the surface and the water therefore enters. When therefore the overlying beds are pierced, the water immediately rushes up, either towards the surface or above it according as the circumstances may admit. This will be clear on referring to the diagram illustrating the principle of these springs; for if the pressure on every part of the surface at

(a) were not equal to that on every part of (c), the water in the two tubes could not remain at rest ; and we know by experiment that a column of water at (c), however small, *will* balance and keep at rest a column at (a), however large.\*

It is evident, then, that although there are several circumstances and several geological conditions by taking advantage of which Artesian wells may be obtained, the principle is the same in all, and the modifications are to be decided on by the Geologist rather than the Engineer. It is for this reason that I have given so minute an account of the principle involved.

With regard to the fact that in limestones, and such like rocks, there do exist great natural caverns, and that even in clayey beds there are alternating bands of sand and gravel capable of receiving a considerable quantity of water, communicating with the surface and sometimes passing down to immense depths, there can be no doubt whatever ; and it is equally certain that in some of them, at any rate, the sheets of water are of very considerable extent.† This is known not only by the examination of

\* This has been sometimes called the hydrostatic paradox, and a very ingenious application has been made of it in what is called 'Bramah's press' by means of which great pressure is produced over a large surface by a proportional pressure upon the surface of another column, the area of the horizontal section of which is exceedingly small.

† As instances may be quoted, 1st. the rock of Torgthal in Norway, which is pierced from end to end (more than three thousand feet) by a rectilineal opening one hundred and fifty feet high. 2nd. The celebrated cavern of Adelsberg, in Carniola, which receives the waters of a river, contains a large lake, and has been traced for a distance of at least six miles, but is probably much more extensive. 3rd. The fountain of Vaucluse, which issues from subterraneous rocks, and pours forth a volume of upwards of thirteen thousand cubic feet per minute, even under ordinary circumstances, and this increases sometimes to forty thousand cubic feet. There is also proof that many of these caverns and subterraneous rivers communicate with the surface, for fish, and even seeds, are occasionally conveyed into them with the water.



such rocks of the kind as are exposed at the surface, and by the appearances they there present, but also from the occasional cavities discovered in boring for Artesian wells, and also in sinking deep shafts in mining districts.\*

As being perhaps one of the most interesting of these, and proving that springs obtained from great depths are sometimes dependant on atmospheric supplies and obtained by means of the peculiar geological structure of the country, I may mention the case of a fountain at Nismes, in the south of France, the supply from which, even in times of great drought, amounts to one hundred and forty-five gallons of water per minute; but it is found that, when it rains heavily at a distance of about six or seven miles from the fountain, in a north-westerly direction, an increase takes place suddenly in the supply, so that it then sometimes pours forth as much as one thousand gallons per minute, the temperature of the water supplied undergoing no change. It is clear in this case that the spring must be fed from a distance, and by

\* As an example of this may be quoted the remarkable head of water met with in the sinkings of the deep coal-pit at Monk Wearmouth, Durham (see p. 339). It is also recorded, that in a boring undertaken some years ago, at Paris, after the work had proceeded at its usual slow rate for a long time, the auger suddenly escaped from the workmen's hands, and they saw it fall upwards of twenty feet, when its top was caught by the transverse handle, at a place where the orifice was smaller. The rapid ascent of the water soon explained the cause of this accident.

During some sinkings near Dieppe as many as seven great sheets of water have been tapped; and under the city of Tours there appears to be distinct evidence of the existence of a subterraneous river, for on one occasion the fountain in the Place de la Cathédrale (sunk to three hundred and thirty-five feet), brought up portions of vegetable matter, among which were branches of thorns an inch or two long, the stems, roots and seeds of marsh plants and different kinds of grain; and fresh-water and even land shells were also found mingled with these remains, which from their condition appeared to have been several months under water.

means of long channels, which allow the water to flow rapidly through them. The rapidity of communication also is so great, that these channels must in all probability be open.

But if the explanation of the phenomena of Artesian wells here given is the right one, there ought to be a degree of uncertainty as to the result of sinkings carried on even in the same district; for the underground reservoirs cannot always communicate with one another; and, though in many instances they are of very great size, they must occasionally be small and partial.

Numerous examples are on record of this irregularity, and some of them are very remarkable. Amongst them may be mentioned an instance at Blingel, in the valley of Ternoise, in which, of three bores undertaken at the same time, and not very far asunder, one supplied abundance of water, rising out of the earth with a jet d'eau, while the other two have not produced a drop of water at the same depth. In another spot also, a bore having pierced to the depth of one hundred feet, thirty of which was through limestone rock, a beautiful limpid stream of water was obtained, rising in a jet d'eau; but, in a garden contiguous, the same rock has been penetrated to a depth of one hundred feet without success.

The cases of failure are, as might be anticipated, comparatively rare when the sinkings are intended to reach a permeable bed known to rest on one which is impermeable, and to be overlaid by another also impermeable; although even these are not always successful, especially when commenced without a previous consideration of the geological condition and probable thickness of the rock to be pierced. The sinkings in the London Clay however seldom fail to produce a supply of some kind, although

the depth that has to be penetrated for this purpose varies very considerably.\*

Perhaps the most remarkable instance on record of a successful sinking for water, commenced at the instance of scientific men, who, from their knowledge of the Geology of the district, were confident of ultimate success, was the Artesian well lately completed at Grenelle, one of the suburbs of Paris. This work was commenced in 1834, under the auspices of the French Government, and it was calculated that, after passing through the tertiary beds and the chalk, the upper greensand would be reached, at a depth probably of twelve or fifteen hundred feet. Up to the time, however, of the undertaking of this work, no successful Artesian sinking had reached to a greater depth than about one thousand feet.

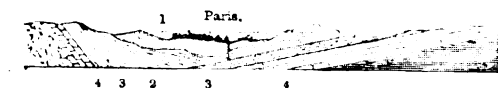
The operation was commenced with an auger of unusual dimensions, (being about a foot in diameter,) and the borings shewed successively the alluvial soil and subsoil, and the tertiary sands, gravels, clays, and lignite, &c., until the chalk itself was reached. The work was then carried on regularly through the hard upper chalk down to the lower chalk with green grains, the dimensions of the auger being reduced at five hundred feet to a nine-inch, at eleven hundred to a seven-and-a-half inch, and at thirteen hundred feet to a six-inch aperture.

\* At Sheerness, water is obtained in the lower part of the London clay at about three hundred feet, and then rises above the level of the ground. At Fulham, the London clay does not appear to contain a supply, but sinkings of about seventy feet in the underlying chalk have been attended with success. At Hammersmith, sinkings to three hundred and sixty feet, and at Chiswick, in the gardens of the Horticultural Society, at three hundred and thirty feet, abundant supplies have been obtained; but in the Duke of Northumberland's grounds above Chiswick no water was obtained at the junction of the London clay and the chalk, nor until the latter rock had been penetrated to a great depth. At six hundred and twenty feet, however, a reservoir was tapped which delivered the water not only at the surface, but about four feet above it.

When the calculated depth of one thousand five hundred feet had been reached, and as yet no result appeared, the Government began to be disheartened, and public patience to be exhausted. Still, upon the urgent representations of M. Arago, the sinking was proceeded with, until at length, at the depth of one thousand eight hundred feet, (five hundred and forty-eight French metres,) the rushing up of a vast body of water offered the most satisfactory proof of the correctness of the principles on which the work was commenced.

The first rush of the water when the stratum was pierced was very violent, an immense volume of water, mixed with sand and mud, and of a very high temperature, rising many feet above the surface. The force, indeed, with which the rise took place was so great, that considerable injury was done to the rods; and it was some time before the shaft was sufficiently cleared for the full discharge to issue without interruption. The spring, however, has been for some time in action; and the volume of water being measured a few months ago, was found to have lost nothing of its force or quantity.

About half a million of gallons are now supplied in the twenty-four hours, and the water has been perfectly limpid since tubes were inserted in the aperture.



SECTION ILLUSTRATING THE ARTESIAN WELL OF GRENELLE.

- |                                     |                              |
|-------------------------------------|------------------------------|
| 1. Tertiary beds of the Paris basin | 3. Upper greensand.          |
| 2. Chalk.                           | 4. Underlying retentive beds |

The above diagram illustrates the Geological condition of the strata in the neighbourhood of Paris with reference to this well.

In all deep Artesian wells the temperature of the water, as it comes to the surface, is warmer than the average annual temperature at the surface, and is also much less affected by atmospheric changes. This corresponds with similar observations that have been made in mines, and, indeed, wherever man has been enabled to penetrate to great depths beneath the crust of the earth. In the unusually deep well at Grenelle, just described, it will not therefore excite astonishment that the heat of the water is very considerable. It appears also to be constant, and reaches 82° of Fahrenheit.\*

There is no reason to doubt the permanency of the supply of water obtained from Artesian wells. As an instance, perhaps the oldest on record, I may mention a spring of this kind at Lillers, in the north of France, which has continued to give the same supply of water, projected to the same height above the surface, for upwards of seven hundred years,—the quantity of water daily poured out at the surface not having been known to vary during that long period.

I have now brought to a conclusion my remarks on that department of Agricultural Geology which has reference to the obtaining a supply of water at the earth's surface; and it will have been observed perhaps by the reader, that the phenomena described and explained, however remarkable they may at first appear, are all strictly in accordance with the ordinary operations of Nature, and

\* Advantage has sometimes been taken of the temperature of water from deep springs, and conservatories have been warmed, and even cress-plots cultivated by such means. It is stated that a salad ground at Erfurt, in which this method is adopted of communicating a regular and high temperature, yields a profit of not less than 12,000*l.* per annum to the proprietor. Fish-ponds have been sometimes improved by such warm springs being passed through them.

immediately result from the action of the fundamental laws imposed upon matter.

But the constant modifications of the action of these laws, owing to the peculiar method of arrangement of the materials which compose the exterior crust of the earth, is another subject which required notice; and it has therefore been my object in the preceding pages to communicate a knowledge of the method of arrangement upon which the results alluded to depend, since by the possession of such knowledge the practical man is able to apply the science of Geology in the ordinary operations of his profession.

All the phenomena observed in the study of the Natural Sciences are thus found to form links in the great chain of events; all of them may be traced to the operation of a few simple, but universal laws; and all work together in harmony to the perfect carrying out of the whole system.

Although, however, indications of this harmony and unity of design in Nature are very often to be traced, perhaps there are not many departments of practical science in which they are exhibited more beautifully, or in a form better adapted for simple illustration, than that which is now under consideration. By a succession of contrivances not difficult to follow, we find that a portion of the water, which at one time forms part of the great ocean, and there holds in solution certain salts, is as it were distilled, and at the same time absorbed, during the passage of a current of air over it. Held in solution in this way, the water taken up becomes for a time an integral part of the atmosphere, and no doubt assists in producing those constant changes in its electrical state, on which so much of its usefulness in many ways depends. Carrying with it this supply of moisture, the current of air having passed over the sea,

reaches at length the dry land, where it is exposed to the action of many causes, both mechanical and chemical, until at length, owing to other changes thus produced, it becomes incapable of longer retaining the same quantity of moisture in solution, but is still able to convey it along mechanically as vapour, in which state it becomes visible, and forms what we call a cloud.

In this manner the watery vapour continues to float over extensive tracts of land, or remains suspended in mid air, until at length the atmosphere is unable any longer to sustain its load ; the particles of vapour, aided also in this no doubt by electricity, then collect together into drops, and sink to the earth in the form of rain.

Of the rain thus deposited upon the earth's surface a large proportion falls on mountain sides, (to which clouds are readily attracted,) and thence runs down in rills to join larger streams, which at length become rivers, and so this portion is either returned once more to the ocean or is reabsorbed by the atmosphere.

Another part, also very large, falls on the thirsty soil, and becomes immediately one of the means of sustaining vegetable life ; and this part, undergoing chemical change, does not reappear in the form of water.

But there is a third portion, which has other duties no less important to perform. A considerable quantity of the rain that falls sinks gradually or immediately into the earth, and owing to that arrangement of the rocks and stones and clays which we have been discussing, it is received into the permeable strata and internal reservoirs of the earth, as into a well-contrived magazine, and is there retained for a time, until at length it is given out gradually in gentle streams which help to fertilise the earth, or are poured forth to supply the wants of man, when, by

the exercise of his ingenuity, he is able to profit by the admirable resources of Nature.

The internal structure of the earth is thus made available in a manner which could not readily have been anticipated, but it only requires a little consideration to perceive how exceedingly necessary to the fertility of continents or other extensive tracts of land is this peculiar arrangement of the strata, by means of which the rain that falls sinks into the earth on the high ground and is returned to the surface in the plains.

It may be that before these conditions were fulfilled the surface of our globe, although well adapted for the existence of the lower animals, was not a fit habitation for man.

The subjoined vignette was intended to form a tail-piece to Chapter XII. It represents a view of the Island of Portland, whence is derived the excellent building stone of the upper Oolites.



VIEW OF PORTLAND ISLAND.



## CHAPTER XVII.

GENERAL CONCLUSION. — NATURE OF PHYSICAL GEOLOGY. —  
 RECAPITULATION OF THE MAIN RESULTS OF GEOLOGICAL INVESTIGATIONS.

THE nature of Geology:—an account, that is, of the materials of which the earth's crust is made up; of the order in which those materials are arranged; of the changes in the original arrangement produced by subsequent mechanical violence; of the organic bodies found associated with the inorganic materials; and, lastly, of the practical benefit that is to be derived from knowing something of these facts:—all this has now been stated in as simple and clear a manner as my ability and knowledge of the subject have permitted. It has been my object throughout the present work to set before the reader, in their proper light, these various matters; and I have carefully avoided introducing such disputed points as were likely to create confusion, or require that he should afterwards have to unlearn anything that is here taught.

But although the subjects of discussion have been hitherto thus limited, it is not right that I should conclude without informing the geological student that there is such a science as Physical Geology, and that many of those persons to whose investigations the most important discoveries in Descriptive Geology are due, have also exercised themselves in endeavouring to reduce to a system the observations that have been made, and discover, if possible, the

nature and mode of operation of the laws according to which the earth has, after countless ages, assumed its present condition. But the theories of Geology have not yet been thoroughly confirmed by experiment; nor can this be a matter of surprise when we consider how recent is the date of many of those observations, without including an explanation of which no one should venture to propound a theoretical speculation. It has seemed, therefore, to me, more prudent to avoid all allusion to such theories, than to mention them only to point out their imperfections, and thus perhaps add to the difficulties with which the subject is surrounded.

But it should be clearly understood how far, at present, hypotheses professing to account for geological phenomena must be looked upon as Theories, and how far they may be safely admitted as real explanations; and this is a subject on which I have already offered some remarks, but which also claims a certain degree of attention here.

Sir John Herschel has observed, "The first thing that a philosophical mind considers, when any new phenomenon presents itself, is its *explanation*, or reference to an immediate producing cause. If that cannot be ascertained, the next thing is to generalise the phenomenon, and include it, with others analogous to it, in the expression of some law, in the hope that its consideration, in a more advanced state of knowledge, may lead to the discovery of an adequate proximate cause."\* In this way, "laws of the first degree of generality," as such may be called, are obtained from the consideration of individual facts; and in precisely the same way "Theories result from a consideration of these laws, and of the proximate causes brought into view in the previous process, regarded altogether as constituting

\* Herschel's Discourse on the Study of Natural Philosophy, p. 144.

a new set of phenomena, the creatures of reason rather than of sense, and each representing, under general language, innumerable particular facts."\* I have endeavoured throughout the present work to confine myself to the explanation of phenomena, and the elucidation of laws of the first degree of generality; those of greater generality, the theories of Geology properly so called, not being perfectly elaborated, and the analysis of phenomena, the immediate object of such theories, not having been yet fully effected.

But I must once more repeat, and would press forcibly on the mind of the reader, the important and evident truth, that although the theory is not perfect, the observations, and even the generalisations up to a certain point are, notwithstanding, sound and unquestionable. It is according to the very nature of inductive reasoning and it is the method by which, of all others, the mind advances most surely and most satisfactorily to a conclusion, when, as has been the case in the progress of Geology of late years, observations are multiplied, the explanations of them tested by experiment, and the first processes of generalisation thus established.

But it will necessarily happen in framing inductions, or in other words, in obtaining these laws, that the mind of man, affected much more strongly by certain classes of phenomena than by others, lays hold, as it were, of these, and is inclined to carry out any explanation of them that may seem satisfactory, and apply it to other phenomena with which it has really nothing to do. This has been the case in the infancy of all sciences, and amongst the rest in Geology, and its result, the promulgation of so-called theories from the determination of a single law of gene-

\* Herschel, *ante cit.* p. 190.

ralisation, has thrown into discredit all generalisations whatever. Now, that this too ready assumption of theory is unreasonable and mischievous, few, perhaps, would be found to deny; but it has been so frequently repeated, that the very name of 'Geological theory' has almost become a bye-word to express wild and foolish hypothesis. This alone might have been a sufficient reason for putting out of the question all mention of hypotheses on the present occasion; but I also felt that the science would be more readily understood when expressed as a narrative of facts.

The main points on which I have principally dwelt may be now very shortly recapitulated. In the first place, I have introduced the subject by an allusion to some striking instances of changes now in progress affecting the physical features of various parts of the earth's crust, and the relation that exists between such causes and the actual condition of the surface of the globe. I have then described in general terms the nature of the rocks afterwards to be considered, and the organic remains found imbedded in them; and with regard to these introductory chapters, I would have the reader chiefly fix his attention upon the fact that a certain order of arrangement of rocks actually exists in Nature; and that, with regard to organic remains, particular groups of species of fossils are to a certain extent characteristic of formations.

In the chapters on the Descriptive Geology of fossiliferous stratified rocks, the different geological formations have been passed successively under notice; and I have endeavoured throughout to illustrate the great truth that all these various formations were deposited under water, which sometimes appears to have existed as an extensive ocean, sometimes as a lake, and sometimes as a river or estuary;

and that there has been a degree of regularity, order, and succession, strikingly indicative of a uniform system, perfectly adapted to all varieties of circumstance that could occur.

The general result of these chapters may be thus expressed :—‘ That the greater portion of the earth’s crust, so far as it is at present known, consists of a numerous series of strata overlying one another in regular order, and most of them containing abundantly the remains of organised beings ; and that these remains indicate the former existence upon the earth of animals extremely different from those which are its present inhabitants.’ It also appears that there have been numerous successive creations of species of plants and animals, often similar to those which had before existed, sometimes quite dissimilar, but never absolutely identical.

In prosecuting the subject of Descriptive Geology, and considering that part of the science which relates to crystalline and unstratified rocks, I have next proceeded to describe the nature of those rocks, such as granite and basalt, which exhibit distinct marks of igneous origin ; and their influence both in greatly altering sedimentary strata, and in disturbing and displacing them, as if by mechanical violence. In this part I have shewn that besides those strata which were regularly deposited, and are fossiliferous, there are others of a different kind, but also of mechanical origin ; and others, again, which shew no mark of stratification. It has also appeared that the circumstances under which these latter occur prove that some relation exists between their presence and the marks of mechanical violence affecting the regular strata ; and, lastly, that these causes of disturbance have acted very frequently, and during the whole period of the deposition of the aqueous rocks.

Having completed this review of Descriptive Geology, I have in the remainder of the work confined myself to giving an account of the various practical benefits which may be derived by a due acquaintance with the fundamental truths of Geology; and I cannot but feel that some explanation is due for the manner in which I have ventured to bring this part of the subject before the reader, as well as for the imperfections and inaccuracies that may be traced in the matter itself. I am neither an Engineer nor an Architect; neither an Agriculturist nor a Miner; nor do I lay claim to any of that minute knowledge of detail which can entitle me to be called a 'practical man' on any of the practical pursuits in which such persons are chiefly engaged. But I have endeavoured to make myself acquainted with these pursuits so far as they relate to the science which has chiefly occupied my time and thoughts; and, perhaps, the labour bestowed in this way, and in a careful investigation of the influence of science on art, is not altogether unproductive of good; for, although the scientific man who so employs himself has not the experience of the professional man, he also escapes many of the prejudices of a class; and he has, beyond all doubt, a much greater facility in attaining those comprehensive views, without which the nature of the true relations of the different sciences with one another, and the bearing of them all on the arts of life, cannot be fully understood.

But whatever view may be taken of this matter one thing is quite certain, namely, that, in order to arrive at useful practical results by means of Geology or any other science, clear and definite conceptions of the fundamental truths of the science, and a knowledge of its principles, are essentially and absolutely necessary. Without these, general information and a knowledge of facts may indeed be ac-

quired, and there may be an appearance of familiarity with the subject ; but there cannot possibly exist that kind of knowledge which is calculated to become the basis of sound and useful conclusions.

I would here close this chapter, and take my leave of the reader, were it not that I might seem in that case to make too light of a difficulty which is still felt by many well-meaning persons, with regard to the apparent contradiction offered by some of the results of geological research to the account given in the Holy Scriptures of the creation of the world.

I am far from undervaluing the importance of any difficulty of this kind ; but I would venture to remark on the real danger that must arise to the foundations of our faith, if the conclusions arrived at from the consideration of a large group of observations all tending to the same result, should be set aside by any authority consisting of a mere dictum. The Book of Nature, laid open by the Supreme Being for the study of his intelligent creatures, can only be understood by a careful and minute investigation into the phenomena of Nature ; but the immediate deductions from the study of those phenomena are not less the truth, nor have they less claim to be admitted as unquestionable than the direct injunctions contained in the written volume of inspiration. But I refrain from giving the opinion I have formed on this subject in my own words, and prefer concluding in the language of one whose truly philosophic and religious mind was well adapted to clear up a difficulty, such as that now under consideration, by means of which an undue attention to a form of expression has interfered with the reception of scientific truths.

“ The language of Scripture on natural objects is as

strictly philosophical as that of the Newtonian system,—perhaps more so ; for it is not only equally true, but it is universal among mankind, and unchangeable. And what other language would have been consistent with the Divine wisdom ? The inspired writers must have borrowed their terminology either from the crude and mistaken philosophy of their own times, and so have sanctified and perpetuated falsehood, unintelligible meantime to all but one in ten thousand ; or they must have anticipated the terminology of the true system without any revelation of the system itself, and so have become unintelligible to all men ; or, lastly, they must have revealed the system itself, and thus have left nothing for the exercise, development, or reward of the human understanding, instead of teaching that moral knowledge, and enforcing those social and civic virtues, out of which the arts and sciences will spring up in due time, and of their own accord.”\* I know of no explanation more satisfactory than this of the apparent want of congruity that exists between the simple record of the earth’s creation in the first chapter of Genesis, and the conclusions arrived at by the study of Geology concerning the ancient condition of the earth, during the long period of its existence previous to the placing on it, as its chief inhabitants, a race of rational and accountable beings.

\* Coleridge’s *Literary Remains*, vol. i. p. 325.





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## ERRATA TO VOL. I.

Page 128, line 3 from top, for GRAPOLITES read GRAPTOLITES.

„ 296, note, line 3,	„ <i>arculata</i>	„ <i>aculeata</i> .
„ 320, „ „ 6,	„ <i>colabratus</i>	„ <i>colubratius</i> .
„ 355, line 16,	„ <i>Dr. Urville</i>	„ <i>D'Urville</i> .
„ 497, note,	„ p. 2	„ p. 130.
„ 498, „ last line	„ p. 45.	„ p. 175.

## VOL. II.

Page 63, references to figure, for *g. Polymorphina* read *g. Cristellaria*.

„ „ „ „ „	„ <i>h. Frondiculina</i>	„ <i>h. Polymorphina</i> .
„ 99, line 17, for <i>twenty</i> read <i>twelve</i> .		
„ 480, last line, for ST. HELEN'S BAY read ST. HELIER'S BAY.		

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